PUPILS' PRIOR BELIEFS ABOUT BACTERIA AND SCIENCE PROCESSES;
THEIR INTERPLAY IN SCHOOL SCIENCE LABORATORY WORK

By

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ABSTRACT

School science laboratory tasks involve the use of conceptual frameworks and scientific processes. Shayer (1978) has criticized Nuffield science curricula for their alleged mis-match with the average pupil's cognitive ability to perform laboratory tasks involving scientific processes such as controlling variables. Researchers interested in pupils' conceptual frameworks view the context of the experiment as a significant influence on the pupils' understanding of the experiment and it is thought that prior beliefs may interfere with the pupils' ability to control variables. This study examines qualitatively the interplay between the pupils' substantive beliefs about bacteria, prior to instruction, and their influence on understanding of the scientific processes in a laboratory experiment about bacteria.

Thirty-one pupils in the second year (12/13 year olds) of a secondary school in England were interviewed in order to elicit their substantive beliefs about bacteria. These pupils then followed a series of two experiments taken from Nuffield Combined Science coursework. Nine pupils were interviewed after each experiment to ascertain their understanding of the task they had undertaken. Two groups of pupils for each experiment were audio-taped while they set up the experiment and their discussion of the questions about the task were recorded. Written work was also examined to cross validate views held by other members of the class. It was found that pupils whose prior beliefs included concepts of bacterial life connected with reproduction were able to understand the role of the control in the
experiment. Pupils' concepts of the growth of bacteria were found to be varied. Pupils who held less scientifically based concepts of bacterial growth were unable to explain the use of the control plate. Some pupils who had more sophisticated prior conceptions of growth failed to use them in explanations about the control plate and showed signs that their beliefs concerning the design of the equipment interfered with their ability to understand the role of the control plate. Prior beliefs were found to be a major influence on the pupils' understanding of the experiment.

Teachers are recommended to investigate pupils' prior beliefs of the concepts being taught and encourage pupils to reflect upon the activity engaged in by the pupil during school science laboratory tasks.
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1.1 Introduction

The context for the following study is found in the Nuffield Combined Science curriculum project, an English science scheme that followed from the implementation of Nuffield 'O' level science courses. The Combined Science team, set up in 1966, had the task of synthesizing these materials to provide work suitable for children in the first two years of British secondary schools (ages from 12 to 14). The project work produced by this team has been used extensively in secondary schools as a complete text and as a resource in mixed ability teaching (Booth, 1975) but has received criticism with regard to its alleged mismatch with the average pupils' cognitive operational level (Shayer, 1978). This study has been carried out in an English Secondary School with average ability second year pupils and focuses on children's beliefs about bacteria. It is believed that the context of the experiments used should be interpreted more in terms of the pupil's understanding of bacteria and the scientific procedures involved in the experiments than purely the operational level of the task (Donaldson, 1978). Although this work has been carried out in a school in England, the selection of the concept area, the problem in which the concept is embedded and the issues surrounding the role of the pupil's cognitive operational level in school performance are all applicable to current curriculum issues in science education all over the world (Wollman, 1978).
1.2 Background to the problem

Science curricula for average British secondary school pupils have often been based on other syllabi intended for the child of above average ability. Of the curriculum used in teaching average ability pupils Nuffield Combined Science subject matter draws heavily on the materials developed by the separate Nuffield 'O' level science teaching projects in biology, chemistry, and physics (Charles, 1976). Parts of the biology component Combined Science draws from Nuffield 'O' level Biology which was not designed for the average secondary school pupil (Shayer, 1974).

The result is that tests, like Nuffield Combined Science, include experimental work which, according to Shayer's (1974) analysis require the pupil to have reached the Piagetian stage of formal operational thought in order to understand some of the sophisticated ideas presented. Shayer has argued, based on an analysis of the Nuffield 'O' level Biology curricula from a Piagetian operational perspective, that only the eleven year old pupil with an intelligence quotient of at least 125 would be able to cope with the level of thinking presented in these materials. The rest of the school population, he suggests, would gradually acquire the required formal operational skills at later ages. This would mean that most pupils would have spent two or more years attempting to cope with problems and experiments which required formal operational thinking when in fact they were only capable of using concrete operational strategies to understand the principles and concepts found in these materials. It would appear that some "borrowed" Nuffield 'O' level concepts would be equally unsuitable for the lower ability class as they appear in the Nuffield Combined Science scheme.
In contrast to Shayer's position, outlined above, Charles (1976) claimed the Nuffield Combined Science course could be adopted for use with nearly the whole ability range. His survey, of teachers' and pupils' judgements and intuitions about the course in a large comprehensive school, concluded that most of the Nuffield Combined Science course is suitable and useful for approximately the upper 75 percent of the ability range. Below that it becomes increasingly difficult to adopt the curriculum, and therefore, he argued it would be unsuitable for the lower ability pupils. A similar view was held by Carter (1976) who found the majority of teachers believed that many sections were suitable for second year (13 year old) pupils.

Views held by Charles (1976), Carter (1976), and Shayer (1974) show conflict between teachers' judgements on the suitability of Nuffield Combined Science curriculum materials and Shayer's theoretical analysis which suggests the unsuitability of these materials for the majority of secondary school pupils. Donaldson (1978) sheds light on the situation by citing numerous examples of research work that shows that the context of the problem and the form of language in which it was presented will affect the success in finding the correct solution. She claims that the operational level demanded by a task may be altered depending on the context in which it is set. It is to this issue of the role of context that other researchers have addressed their interest (Driver and Erickson, 1983; Gilbert and Watts, 1983). These researchers suggest that more importance should be placed on how student beliefs are manifest in complex classroom environments and whether student's commonsense concepts become "critical barriers" (Hawkins, 1978) thereby limiting their understanding
of the disciplinary concepts presented by the curriculum. Research is also being directed towards obtaining perceptions of students' difficulties and the understanding of pupils' "alternative frameworks" (Driver and Easley, 1978; Erickson, 1981) regarding the topic and the task we are asking the pupil to approach and master in the classroom.

Although Shayer argues from the standpoint of operational levels being the important criterion as to whether a particular concept will be understood, he nonetheless concludes (Shayer, 1978) that when teachers attempt to find curricula most suitable for their pupils they search for how particular teaching routines match the understanding of the pupil. Researchers interested in pupils' alternative frameworks, although working from a different viewpoint, see that matching teaching routines to the pupils' understanding is also an important goal.

This study examined the pupils' beliefs and strategies used in the classroom while conducting two scientific experiments on bacteria taken from the Nuffield Combined Science Course.

1.3 Statement of the problem
1.31 General problem area

The experiments under study, "Growing Bacteria from the Air" and "Bacteria on Ourselves", constitute two of the experiments in the Combined Science course unit on microbes and are also found in a similar form in many other texts used by average and lower ability pupils in the secondary schools throughout the world.
In spite of Shayer's (1974) claim that similar experiments in Nuffield 'O' level Biology are beyond the operational capacities of many of the pupils, the section on microbes in the Combined Science scheme was judged by curriculum developers to be suitable for average ability pupils although much of the material in this section involves the use of operational schemes found in the Piagetian stages 3A and 3B.

This study will identify student beliefs and strategies with respect to the subject matter and the context in which it is presented. It is anticipated that as a result of the knowledge obtained from this study, teaching strategies may be devised to promote greater understanding of the subject matter.

The student's knowledge of the subject area may play an important role in determining how the pupil interprets the experiments. It is believed the students will already hold some beliefs about bacteria since microbes, although not visible, are often discussed in relation to disease so we may assume that these beliefs might have some influence on how the experiments are interpreted and understood.

Along with beliefs about the subject matter, the pupil's understanding of a scientific experiment (i.e. how one is conducted, what conclusions can be made, what relevence does it hold, etc.) may influence how the pupil approaches the task and interprets the results.

From teaching experience the author recognizes that the pupils find difficulty in interpreting the results of these experiments successfully.
Pupils have shown that they do not recognize the importance of controlling variables in science experiments. Insight into the pupils' use of their knowledge and the alternative roles that they perceive the control plate in the experiment to play could be the result of their concept of a scientific experiment. This could influence how the pupils reach conclusions regarding the experimental data.

Understanding how pupils view experimental procedures may provide the teacher with a new perspective as to how to make other similar tasks more meaningful. Often the teacher is unaquainted with the concepts held by the pupil, or how they were obtained. In turn, the student is often unaware that his beliefs of a curriculum area are mismatched with those of the teachers. In may instances the teacher follows a curriculum assuming that pupils are working within the same framework of the teacher's viewpoint of science. The teacher will often modify the curriculum to suit the ability of the pupil without being aware of the alternative frameworks belonging to the pupil. It is hypothesized in the present study that these frameworks have more importance in understanding the nature of the difficulties experienced by pupils in particular content areas than has been generally recognized.

1.32 Specific research questions

The specific research questions that this study addresses are as follows:

1) What are the beliefs that pupils possess concerning bacteria before being formally taught? and
2) How do pupils' beliefs concerning bacteria interact with their understanding of experimental procedures involved in the two experiments used in this investigation?

More specifically, the following aspects of the experimental setting will be examined:

a) methods of identification of bacteria,
b) bacteria as living units,
c) significance of sterile equipment and medium,
d) significance of a control in the experiments, and
e) pupils' overall understanding of the experimental procedures.

1.4 Some general methodological issues

The study was conducted in an urban English secondary school with pupils of the second year (12-13 years old). These pupils were of average ability (based on streamed classes in the year) for the whole of the school aged population. None of the pupils had been taught formally any aspect of the syllabus pertaining to bacteria prior to this study. Pupils had experienced teaching sessions concerning the concept of life in their first year of secondary school. During this period of time they would also have had limited experience in laboratory practical work involving controlling variables. It is thought that the substantive beliefs elicited by the interview technique of the first clinical interview can be generalized to other groups of children of similar backgrounds and experiences. Given the types of comments made it would appear that the experiences these pupils used in responding to the interview questions (e.g. citing experiences from viewing television programmes, discussion
with health professionals) would be typical of most school pupils of this age in Britain and other western countries. It is expected that after following the same topic in the curriculum project based laboratory work that pupils of average ability would reach conclusions and hold similar beliefs and assumptions about bacteria and the scientific processes of the two experiments studied. The teaching experience of the author lends support to these observations.

The strategy adopted to collect information concerning pupils' beliefs and how these are used in one particular set of laboratory tasks has been labour intensive. The data gained has revealed a richness in meaning that could not have been obtained by less time consuming techniques. The author is conscious of the possible criticism of this type of research. The number of subjects involved in the interviews was relatively small and this raises questions to the restricted nature of the findings. An attempt at the cross validity of data was made by the use of written work both from group tasks and individual assignments. An understanding of the nature of the problems in teaching and learning can only be gained by intensive study of specific problems. Larger scale procedures tend to lack the required sensitivity needed to investigate actual learner problems and difficulties. A range of accurate descriptions of these problems and difficulties together with precise information as to the context in which the problems or difficulties occur will be considerable use both to teachers and to curriculum developers.
CHAPTER TWO

2.0 Psychological context

2.1 Cognitive issues versus conceptual issues

In the United Kingdom new examination syllabi have placed demands on basic scientific skill development. Along with this trend there has been an increasingly obvious interest in Piagetian developmental psychology and its curriculum development. Piaget's stage theory produced the hope that instruction would become more successful if learning tasks matched the cognitive stages already reached in the pupils' psychological development. Other researchers interested in pedagogy but not agreeing with Piaget's emphasis on the stages of cognitive development have sought alternative theories for improving teaching. Many of these researchers (e.g. Novak, 1977a; Wollman, 1978) have criticized the use of Piagetian theory as a base for research and have claimed that it is ill-suited to finding ways of improving instruction since the veracity of the stages have been questioned by many (Brainerd, 1978; Brown and Desforges, 1972). It has been suggested that the concept of stages should be used for descriptive convenience only (Toulmin, 1971). Little is known concerning the rules of transition from one stage to another despite Piaget's mechanisms of stage transition. Discrepant evidence supporting the idea that Piaget's operational structures can be widely taught leaves the question of transition a lively topic for debate.

With the development of the Nuffield Science schemes and their "modification" to suit the average secondary school pupil, researchers in
curriculum development with a Piagetian bias asked several questions: "Was previous practice in science teaching, developed by adaptation to the top 15-20 percent of the school population, a satisfactory model for the other 80 percent of pupils? Was it possible to keep our existing models of science education while modifying them suitably for the less able pupil?" (Shayer, 1979). Piagetians maintain that learning takes place most effectively when the child's present conceptual level (cognitive structure) is matched closely with the operational demands of the subject matter. Shayer (1974) assessed the section being studied in this thesis, bacteria and disease, as requiring a 3A minimal conceptual age and that the tasks being demanded of the child were at least one year ahead of the cognitive development of selective pupils (top 15-20 percent of school population). This suggests that pupils not attaining levels of formal thought will not gain as much from the experience as those already at this Piagetian stage. Great interest has been shown in the match of science curricula to the learner in the middle and secondary school. This match is said to have been achieved through an operational analysis of the curriculum and the assessment of the pupil.

2.11 Piaget's work as used by Shayer

Shayer's research program (Concepts in Secondary Mathematics and Science, 1974-1979) developed methods for analysing the curriculum and assessing the level of thinking of the pupil population. Both the analysis and assessment have been criticized with respect to experimental design and Shayer's heavy reliance on a Piagetian framework (Driver, 1979; Wollman, 1978). This framework was used as it was thought possible to analyse both the demands of the curriculum and provide a method of
estimating the cognitive level of the pupil. The underlying model of CSMS work assumes Piagetian tests do test cognitive development. Shayer (1981) rejects the alternative interpretation that the Piagetian tests measure the pupils' grasp of concepts they have learned and not cognitive development.

A taxonomical method was implemented for analyzing the Piagetian level of thinking demanded by a Science Curriculum (Shayer, 1972). This was achieved by assessing the level of operational development possessed by the child in Piagetian terms then predicting the supposed Piagetian level of thinking demanded by an examination of the content objectives and exam items of the course. The exam items were classified beforehand for supposed Piagetian cognitive stage development required for their comprehension. Only pupils at the 3A stage of formal thought were considered to have an opportunity to succeed on tasks designated as being 3B in cognitive demand.

Criticism has been leveled at this analysis (Driver, 1979) since the logical demands of the task may not be problematical to the pupil but the context in which these demands lie, due perhaps to the pedagogical approach adopted, may cause the pupil to be unable to cope with the cognitive task. Other researchers have suggested that memory demands may affect the logical performance on a problem (Pascual-Leone, 1969). Formal stage performance may reflect acquired knowledge to a greater extent than acknowledged by Piaget (Wollman, 1978). One of Wollman's criticisms of placing tasks in levels of cognitive demand is that in a statistical sense, the within group variance of the tasks is too great to be useful.
He claims that Shayer's methods "have relied on either the prima facia similarity of a school concept within a Piagetian one or the researcher's best guess as to the difficulty of the concept. Since most school science concepts are not very similar to Piagetian concepts, informed guesswork has been the method of choice" (p. 42).

In Shayer's work the second component of the research, the method assessing the pupil's level of thinking, required the development of group tests along with data collected from a large enough population to be representative of secondary school pupils. Data concerning the development of thinking abilities in these pupils was essential for curriculum matching as it was impractical to think that the original Genevan work (Inhelder and Piaget, 1958), assuming that all adolescents reached formal thought, would apply in Britain. Instead, it was assumed that any level of thinking from pre-operational to late formal operational might be shown by different pupils. About 30 percent of 15 year old pupils demonstrated formal thinking ability with the rest showing a wide spread of cognitive ability (Shayer, Kuchemann, Wylam, 1976; Shayer and Wylam, 1978).

Driver (1979) criticizes the establishment of national norms as a hazardous procedure especially when only two tasks are used in the assessment testing early (3A) or late (3B) formal thinking. There is a danger that pupils may perform indifferently on one or other of the tests and be classified as non-formal. An earlier attempt by Shayer (1974) used IQ scores as a classifying standard. The general finding in this area is that Piagetian tests sometimes correlate moderately with IQ and scholastic
achievement but again are not sensitive enough to be generalizable.

Alternative theorists in cognitive development have objected to the classification stages of the Piagetian model. Shayer (1979) has realized the doubt cast on the validity of Piaget's work by other researchers (Lunzer, 1973; Brown and Desforges, 1977) but in taking a "very hard nosed empirical view" and using Piaget's experimental methods, his idea was to show that performances at the same Piagetian level from task to task would be maintained. In his summary of the empirical evidence he claims support for Piaget's account of formal operational thinking.

Piaget's formal operational stage has come under heavy criticism from other workers. Odum (1978) suggests that the problem of decalage (i.e. the concept is achieved with different tasks at different times) has proved decisive in the downfall of the usefulness of the stages of Piaget's theory. The theory is unable to predict performance and performance is the ultimate criterion for judging learning outcomes. Performance variability on tasks, supposedly demonstrating formal thought, have limited our knowledge of developmental theory, argues Wollman (1978). Grouping tasks in the same logical classifications has been seen to be unwise since from a performance perspective they are not all equivalent. Piagetian logical operations have been shown not to relate to performance and many researchers (Falmagne, 1975; Brainerd, 1977b; Revlin and Mayer, 1978; Siegel and Brainerd, 1978) have argued the insufficiency of concrete and formal logical operations on the ground that the postulated stages fail to show their discreteness. Piaget's description of formal operations is quite confusing and it is difficult to understand the exact
meaning of the term. There is considerable question as to the time of emergence of the formal operation dealing with verbal propositions (e.g. if then statements). In respect to the INRC problems, Easley (1964) noted the occurrence of this ability much earlier than Piaget would maintain.

Increasing numbers of studies show that abstract or formal operational tasks can be handled by young children. Ennis (1976) has shown that children in grades 1-3 (6-8 years) can use forms of conditional logic and Kuhn (1977) has observed that conditional reasoning can take place in concrete conversational situations. Donaldson (1978) suggests that thinking which no longer operates in a supportive context and is often called 'formal' or 'abstract' should not be equated with 'formal operational thought' as determined by Piaget, but should instead be termed disembedded. She cites more evidence that the context of the task is as important as the task itself when attempting to classify a task as eliciting formal operational thought from a pupil. Munby's (1980) criticism is that the research community is running the risk of being careless if the notion of being at a stage is used. The ambiguities in research reports abound as to who will have reached formal operational thought by a certain age and what forms of reasoning constitute this stage. Munby reports that the temptation is to "take things quite literally, to lose sight of the syntax and to begin to award the notion of stages a status it does not deserve" (p. 130). The designing of curriculum and teaching strategies according to definite stages may be unwise especially in the light of views held by Brown and Desforges (1977). They make the point that "the exact proportion of heterogeneity which theorists will tolerate without abandoning the stage concept, is an
interesting one" (p. 11). This statement lends support to Driver's (1979) criticism of Shayer's use of tasks to analyse the middle and secondary school population, claiming that tasks used were not successful in defining formal thought to a particular level and cannot be compared to class tests due to their differing contexts.

It is doubtful if Piagetian stages can be used as indicators of "readiness" for sequencing subject matter in the curriculum. The discussion of sequence revolves around the question of how concrete or abstract the learning experiences must be at various stages of development. We have already seen evidence that tasks vary in their cognitive difficulty depending on their context. Many educators treat Piaget's observations as if they are final statements in the theory about intellectual development and these observations are then used to determine content of the curriculum without considering other evidence or holding reservation. Appraisal of Piaget's implications shows the structure and sequencing of subject matter as somewhat pessimistic.

2.12 Alternative perspectives

Theorists like Shayer are mainly concerned with the development of frameworks for studying cognitive development. Acceleration of cognitive development is effected by basing the teaching-learning process on theory. Piaget's educational contribution is in the area of structure and sequencing of subject matter at appropriate developmental levels. Many researchers have spent a lifetime's work suggesting pedagogical strategies to promote efficient learning in contrast to the Piagetian ideas of matching the level of difficulty of the task involved with the cognitive
development present in the child's thinking capabilities. These researchers see the problems as more content and context specific and have spent time investigating topics which create teaching difficulties.

Gagne, Ausubel, and Bruner place less emphasis on Piaget's operational structure but more on how information is processed. Ausubel (1963, 1968) does not view his theory in opposition to Piaget's. The key issue is "whether children develop general 'cognitive structures' or 'cognitive operations' to make sense out of experience, or if instead, they acquire a hierarchically organized framework of specific concepts, each of which or some combination permits them to make sense out of experience" (Novak, 1977b, p. 455). Novak believes that children acquire a hierarchically organized framework of specific concepts and do not develop general cognitive operations as Piaget's theory claims. Similarly for Bruner (1965) the structure of the topic lies in the discipline considered; how things are related within a particular discipline. Piaget's concept of structure differs from Bruner's since Piaget develops the idea of the child actively structuring his experience through the operation. "An operation is thus the essence of knowledge, it is an interiorized action, which modifies the object of knowledge..." (Piaget, 1964, p. 8). For Piaget the concept of structure is a property of the child's mind. Duckworth (1964) contrasts Bruner with Piaget on the idea of structure in the curriculum:

"The question comes up whether to teach the structure or to present the child with situations where he is active and creates the structures himself.... The goal in education is not to increase the amount of knowledge, but to create the possibilities for the child to invent and discover" (Duckworth, 1964, p. 3).
Since every pupil has their own way of structuring and attempting to decipher the world around them, a class will possess many unique learning styles and viewpoints. Readers of Piaget can conclude that the child structures the world in ways quite different from adults. Appreciation of other types of concept construction may facilitate the communication of knowledge. Bruner (1965) remarked that if we present topics in the way children perceive things then the subject can be taught effectively underlining the basic concepts. Unfortunately teachers often do not know the child's viewpoint. Bruner's method of teaching is to induce understanding by tying down isolated segments of knowledge. The development of basic transformations of cognitive structure is not in terms of S-R bonds as in Gange's tradition but of organized wholes and systems of inter-relationships. The action of the person on the environment leads to the development of a cognitive structure with this structure possessing an equilibrium and greater balance between ideas. The optimum sequencing of this action is not step by step, in Bruner's view, but to allow the pupil the opportunity to organize their own learning according to their own requirements. Bruner advocates the spiral curriculum so that by the time subjects are presented a second time the pupil's knowledge has both broadened and deepened and therefore becomes more specialized. This style of learning places emphasis on the child to discover and learn.

In contrast, Ausubel sees the teacher as being more influential. Piaget's ideas about verbal learning place severe limitations on the curriculum maker. Bruner, however, is optimistic concerning the role of language as a coordinator and integrator of experience. Likewise
Ausubel's perspective is more of an interactionist approach using verbal, didactic learning to aid the formation of concepts. He criticizes the Piagetian view for over emphasizing the person and behaviourists for their heavy emphasis on the influence of the environment. Ausubel et al. (1978) have concentrated on cognitive process in school learning and describe the pupil as fitting new units of information into a category of preconceptions already held by the learner. New learning is seen as a process of subsumption by preconceptions (Ausubel, 1963). From studies reviewed by Driver and Easley (1978) there seems to be reasonable grounds to suggest these preconceptions may be resistant to instruction. Since "new learning" is related to a large array of information the pupil already possesses (Novak, 1976) it is understandable why confusion arises in obtaining the 'correct' concepts when their prior conceptions are often based on a very different perspective of the world. The task of the school, explained by Ausubel in his meaningful verbal learning (1963), is to identify clear, stable, and organized bodies of knowledge within disciplines so that the learner incorporates them meaningfully into his own system. Meaningful verbal learning depends on the nature of the material learnt, whether abstract or not in nature, and the availability in the subject's cognitive structure of relevant subsuming concepts for those being taught. The two criteria of non-arbitrariness and substantiveness gives the material its logical meaning. Its non-arbitrariness is the relationship of the new item and its congruency with the person's existing ideas whilst substantiveness concerns the meaning of the relationship withing different but equivalent semantic contexts. With this theory of concept acquisition Ausubel recommends the use of advanced organizers to structure and sequence instruction but prior
to this, the teacher should possess some insight into the knowledge possessed by the typical pupil.

Discovery of the child's point of view is also a recommendation made by Margaret Donaldson (1978). She cites research which claims that children given a task with "human sense" i.e. a problem that does not possess abstract terms, the task will be more satisfactorily solved and the pupil shows less egocentrism and inability to decentre. Piaget considers that the growth of the ability to decentre is crucial since the making of inferences demands skill in the flexible shifting of point of view. Donaldson claims that there is good reason to doubt whether the child's difficulty with decentring is as severe and widespread as Piaget claims. In order to improve the acquisition of skills it is suggested that the child understand the general nature of the learning activity. This makes great demands on the teacher's capacity to decentre since

"an adult's knowledge of the general nature of the subjects taught to children when they first enter school is apt to be so well established that it blocks the realization of precisely what the children need to be helped to see"

(Donaldson, 1978, p. 100).

This could be the case in secondary schools as well. The child's approach to science may be determined by the concepts he/she sees as important and not those that the teacher sees as necessary. The significance of scientific procedures may not be relevant to the pupil in the science laboratory. Teachers need to gain insight into what pupils consider relevant in order to make science more meaningful.

Making school science meaningful has been the purpose of the two dominant viewpoints that have influenced research on learning and problem
solving. Piagetian researchers such as Lawson (1975, 1979), Renner and Stafford (1972), and Walker, Hendrix and Mertens (1980) argue that the developmental stage of a student can be used to predict or account for success or failure with particular aspects of science. Those researchers in the Ausubelian tradition (Novak, 1977c) argue that relevant prior conceptual knowledge is the most important factor in learning science content as well as using that knowledge to solve problems. The relationship between students' conceptual knowledge and problem solving strategies is emerging from a third perspective. As an example, Greeno's (1978a) work emphasizes the interrelationships between the conceptual knowledge possessed by problem solvers and their knowledge of the procedures they use to solve problems. He calls this meaningful problem solving. Detailed analysis of the conceptual and procedural knowledge that students use and learn from instruction may provide further basis for changing science instruction.
2.2 Concept learning

There is considerable evidence from recent research of the important role played by the ideas that children bring with them to school. It is not sufficient to limit oneself to the discovery of specific deficiencies inherent in student's viewpoints compared with the expert's knowledge, but for every lesson the teacher should attempt to appreciate the many mental and physical processes that are prompted into action in order that the lesson be effective in terms of the teacher's aims and objectives.

The aim of every teacher is to promote the pupils' acquisition of correct scientific concepts. When a concept has been meaningfully learnt or acquired the student can define its critical attributes and consequently recognize new, unfamiliar instances of the particular concept (Bruner et al., 1956; Ausubel, 1968; Klausmeier et al., 1974; Herron et al., 1977). Klausmeier (1976) has produced five levels of concept mastery based on the pupils' ability to define the attributes of a concept. The everyday use of language can hinder the ability of the pupil to define the attributes of a concept (Vygotsky, 1962). An example of this is the often used false distinction between animals and birds. The ability to assign birds to the same group called animals requires the pupils to remove the division placed by everyday language and assign examples to their class on the merits of their defining attributes. The ability to assign correctly to its class examples of the concepts is required in the third of the five levels of concept mastery proposed by Klausmeier (1976). The five levels of concept mastery according to Klausmeier (1976) can be summarized as follows:
Level 1  The ability to use the word correctly or respond to it appropriately in conversation.

Level 2  The ability to give spontaneously, examples of the concept, e.g. to provide examples of living things.

Level 3  The ability to assign correctly to its class examples of the concept, e.g. to classify living or non living things.

Level 4  The ability to give verbally some basis for the classification, e.g. to say what living things do that non living things don't.

Level 5  The ability to classify instances and non instances accurately and to show full knowledge of all the defining attributes of the concept.

In the process of concept learning there may well be a requirement for the individual's conceptual framework to undergo change in order that the biological concept becomes more precise.

Within the epistemological framework of conceptual change there has been developed two mechanisms of change - the "revolutionary" and the "evolutionary" process. Strike and Posner (1982) regard the deep restructuring of knowledge by the learner as a "large scale" change of 'accommodation'. This revolutionary change would be hindered by existing beliefs acting as 'stumbling blocks' (West, 1982) and would seem a drastic conceptual process. In contrast, the evolutionary change tidies up the student's beliefs and these may even provide the 'building blocks' (West, 1982) for change. The "small scale" change or "assimilation" that Strike and Posner (1982) suggest may be prompted when teachers attempt to link old and new knowledge.
In order to understand the difference between pupils' beliefs and teachers' beliefs, teachers may need to know the beliefs students bring to the classroom and the concepts that are to be learnt. In the experiments investigated by this study there are three broad components that may influence the pupils' understanding of the results of the experiments. These are: 1) prior beliefs held concerning bacteria, 2) the cognitive procedures used in isolating variables and controlling them, and 3) the demands of laboratory work, e.g. using new apparatus, accommodating new instructions, both written and verbal.
FIGURE I  Sample concept map produced by teacher for comparison against pupils' concept maps
2.21 Pupils' concepts of bacteria prior to instruction

It is possible to examine the many concepts associated with the term bacteria by generating a concept map. The concept map represents one person's understanding of that term. Figure 1 illustrates a concept map produced by the author. The terms in the boxes are concepts and these are connected by propositions to other concepts. A comparison of a typical map drawn by a pupil with that of one drawn by the teacher may assist the teacher to understand better some of the difficulties experienced by pupils in interpreting a given instruction problem. For example, to understand the role of bacteria in the experiments the pupil must have some understanding of the concept of "living things" and size of "bacterial organisms".

2.211 Pupils' concepts of living things

Although there has never been a single definition of the concept of life that would be satisfactory to many biologists, seven characteristics of living organisms used in school are 1) growth, 2) reproduction, 3) respiration, 4) nutrition, 5) excretion, 6) irritability, and 7) locomotion. These seven characteristics better illustrate the animal kingdom at multicellular levels. It is not surprising that the concept of bacteria as a living unit may be more difficult because it is not obvious that they comply with any of the above characteristics since they are so small. Piaget (1929) identified four stages which characterize the development of the "life concept" in children. The final stage achieved by eleven year old children and upwards showed the ability to correctly identify only living creatures as being alive and possessing
consciousness.

Life has many meanings as far as children are concerned. From a study of 83 students, grades 5-9, 45 percent understood the continuity of life (Tamir et al., 1981). Thirty-six percent realized that living organisms originate from other living organisms, but were not able to explain this relationship. Nineteen percent believed that "it is possible for living organisms to develop from nonliving". Ninety-nine percent of children from grade 4 classified animals as living.

Simpson and Arnold (1982) found all the primary pupils interviewed could use the words 'living things' appropriately. They found that the performances of pupils in the first two years of secondary school (12 and 13 year olds) were not markedly improved in the classification of living and non living over the primary pupils. Fifty percent of the fourth year (15 year olds) biology pupils were still unable to correctly classify eighteen items. "A" level students found difficulty in distinguishing between 'alive and dead' and 'dead and non living' in set tasks (Brumby, 1982). Even children who correctly classified sixteen items as living and non living "possessed an imcomplete understanding of living according to associated biological attributes (such as) nutrition ... respiration ... reproduction" (Looft, 1974, p. 289).

2.212 Pupils' classification of living things

Researchers have also examined pupils' ability to classify living and non living objects. It appears that it is easier to classify animals as living organisms than plants. The ability to classify has been regarded
by psychologists as an important aspect of the cognitive process. It is based upon the formation, by the pupil, of precise concepts and the development of systematic ways of relating them to each other (Lovell, 1968). Gagne (1970) suggests that there are two kinds of concepts: those of a concrete type that are derived from the experience of many examples, and those of a defined type that are more abstract in nature and derived from definitions. Some classes of living organisms are of the concrete type since real or pictorial examples can be presented whereas other classes of living organisms rely on verbal definition e.g. the difference between amphibians and reptiles.

Ryman (1974) found that many twelve year olds in a comprehensive school were unable to classify plants and animals into classes. With a few exceptions they did not possess reliable class concepts. This was revealed by their inability to recognize instances and non instances of the concepts. The misunderstandings revealed suggest that inadequate concept formation and language problems contribute to the difficulties of classifying plants and animals. The classification of starfish and jellyfish as "fish" illustrates this problem. A study of thirty-nine ten to fifteen year olds revealed that all but six used the number of legs to categorize instances and non instances of the concept of "animal". The common meaning of the word "animal" appeared to refer to the restricted category of the four-legged, terrestrial mammals. Size was used as a criterion by approximately one third of the pupils at least once. Results showed that the smaller the organism the less likely it would be animal. A few pupils used the criterion of movement as an attribute of living things (Bell, 1981).
Simpson and Arnold (1982) and others have shown that pupils who have experienced two years of secondary school science do not possess a precise concept of living things, despite the fact that their science courses were designed to teach this concept. There was also a considerable gulf between the level of concept attainment actually reached by the pupils and the level of attainment assumed by the teachers. It is unlikely to be useful to commence teaching about bacteria in the second year when "living" is a vague, unstable concept, the word "animal" takes on diverse meaning, and bacteria in their physical sense are so small as to be non-existent.

2.22 Pupils' ability to isolate and control variables

The procedures of classification, hypothesizing, sorting out relevant material from experiments, analyzing data, etc. involve not only conceptual understanding but use cognitive processes (Imenda, 1984). These processes may provide the framework for a set of ideas or rules that can be used to interpret and explain data obtained in a given situation. According to Piaget the highest cognitive process - formal operations - allows reality to be critically examined from a sense of the many possibilities that it contains. With formal operational capabilities, the pupil can handle complex problems consisting of three or more variables by controlling all but one of these variables and examining the influence of the uncontrolled variable.

Although Piaget's stages of cognitive development have come under close scrutiny and have not provided a panacea which some researchers had expected, some insight has been provided into pedagogical problems concerned with pupils' cognitive development. A relevant problem in
teaching science is the child's ability to control variables; to keep all but one variable the same so the effect of one variable can be investigated. According to Piaget, as cognitive maturity is attained in a variety of concepts there is a shift in the reasoning about real or observed events to reasoning about all the possible events in a given situation. The less mature pupil is limited to reasoning about the specific content of the problem because he cannot generalize and apply an organizational principle learned about one variable (e.g. length) to another variable (e.g. weight). In contrast, cognitive maturity brings the capability of organizing any data, even verbally presented information, by using generalized principles. The pupil can separate the individual variables of the problem and consider the possible effect each variable might have. When the pupil reasons about these possibilities, he is not dealing with the objects themselves, but with their "truth values". The pupil must therefore use propositional logic.

In agreement with Inhelder and Piaget (1958), Treagust (1979) argued that propositional logic is a fundamental part of formal reasoning. Inhelder and Piaget have observed that the pupil who has obtained formal operations can use 16 operations of propositional logic. Of these 16 operations the biconditional (if and only if) is used in scientific hypothesis testing. The reasoning behind hypothesis testing would seem to require that an individual knows what is expected assuming the hypothesis is true. Lamb and Betkouski (1980) suggest that once one knows this then he is in a position to compare the expectations with actual results. Probabilistic and proportional reasoning should develop only after biconditional reasoning as they involve more complex operations such as
mentally formed relationships and comparisons. The ability to form relationships and comparisons is propositional logic and is essential for the success in the skill of controlling variables. However, Ennis (1975), in an analysis of Piaget's schema, showed that the ability to "handle propositional logic" in Piaget's terms does not differentiate young children from adolescents. Some of the complex operations are used correctly by seven and eight year olds, others are used poorly by adolescents. Ennis concludes "there appears to be no connection between isolating variables and possessing the combinatorial system". Further support for the inadequacy of the 16 operations in explaining formal operations comes from Osherson (1974). Using a series of related logical problems the research attempted to predict success and failure based on which operations were needed to solve each problem. He found this approach inadequate for predicting patterns of success in individual subjects.

It is possible that the concept of a controlled experiment develops early in what Piaget calls the concrete stage of development with the idea of a fair comparison. Fairness is an essential concept required in the control of variables. Wollman (1977a) found that students remain unaware of general criteria of fairness even when they are capable of correctly judging a variety of comparisons as fair or unfair. Also lacking was a clear idea of how to explain or determine the causes of an event. Students were found not to analyze the event in terms of a complete set of variables. Even when these are specified, they do not then systematically determine the roles of the variables by varying them one at a time. Piaget's formal stage is supposed to remedy this situation and development
seems to take place along systematic lines.

In a school based project Kamm (1971) concluded that a programme on microbes appeared not to have fulfilled its secondary aim of teaching pupils how to isolate variables and the need for controls in scientific investigations. This study concluded that children automatically and progressively attain the ability to isolate variables as their mental ages increase and that this is not a process that can be speeded up since in "training" it was found that transfer of reasoning from one particular problem to another was slight.

Key ideas presented in other research (Wollman, 1977a, 1977b) suggests that 1) even very young children have acceptable strategies for solving some controlling variables tasks and 2) a principal dimension of difficulty may be the amount of information simultaneously in demand. Based on a method of task analysis devised by Pascal-Leone (1970), Case (1974) obtained evidence supporting the contention that on the controlling variables task the specific performance may be limited by the capacity for processing information. Case (1974) conducted a training study in which the separation of variables procedure was taught to seven and eight year olds. Responsiveness to training was related to the match between attention demands of the instructional method and the working memory and attention capacity of the subjects. Case's subjects dealt with three informational items or three schemes at the same time. A similar set of items for this study could be:

1) Why does bacteria grow on X-1 plates? (X = the total number of plates)
2) It could grow because the air let in has bacteria
3) It could grow because the agar wasn't sterile.

Case (1974) found that pupils whose working memory was only capable of dealing with two items at the same time failed to profit from the instructional procedure. The next phase of the training programme was followed by those pupils successful in dealing with the three information items. These pupils learnt to deal with an added information item. For example,

1) Why does bacteria grow on X-1 plates?
2) It could grow because air let in had bacteria
3) or the agar wasn't sterile
4) If the agar was the same; it can't be the agar.

When demands did not exceed capacity, training was very successful, otherwise it was not. Case's methods dealt with "chunking" of information items and making new items salient. The subject becomes accustomed to taking account of this. New ideas, new schemes are introduced simply in the context of a familiar background. This necessitates that the tasks to be taught must be carefully analyzed. The learner's initial knowledge level needs to be ascertained and learning activities logically presented to bring the learner from his initial state to the desired state. At each step in the learning process care is taken to minimize the information load on working memory. Case's approach differs from that of most Piagetian influenced education researchers since there is no attempt to classify learners as concrete or formal. Instead, Case's developmental approach "advocates assessment of the learner's initial state in terms of the strategy which he applies to the criterion task spontaneously" (Case, 1974).
Two important features of Case's (1974) work are that the information is "chunked" to make salient items and that any new information is absorbed into a familiar background. Case believes that the ability to control variables may be context dependent. Therefore, it is important that teachers at least ensure that pupils understand the basic variables presented in the context before expecting them to apply a general strategy of controlling variables. Understanding the basic variables in the context of this study would require the pupil to understand the living nature of bacteria, their distribution in the air and equipment, and the concept of sterilization.
2.23 The demands of pupils' work in the science classroom

The differences between scientists' science, school teachers' science and school pupils' science (Gilbert, Osborne and Fensham, 1982) create dilemmas which require addressing if progress in science education, in the area of concept acquisition, is to be achieved. For many pupils school science is an obscure activity full of statements which are difficult to make meaningful and worthwhile (Watts and Gilbert, 1983).

Teachers attempt to promote conceptual change in their classrooms toward more correct scientific views. Much current research into how this process can be achieved has been based on an epistemological framework derived from recent development in the philosophy of science often labelled the "conceptual change" viewpoint (Kuhn, 1970; Toulmin, 1972; Lakatos and Musgrave, 1970). The conceptual change belief can be summarized as follows:

1) Individuals approach any inquiry with their individual prior conceptions,
2) The nature of these conceptions significantly determines the nature and the products of inquiry,
3) Inquiry, rather than being an accumulation of facts, is the transformation of current knowledge, and
4) Rationality consists in viewing new problems, ideas, and practices against a background of accepted conceptions and beliefs (i.e. against a tradition or heritage) (Posner, 1982, p. 107).

Children have been encouraged to change their concepts by interacting
with their environment. Laboratory work appears to be a perfect opportunity for creating conceptual change. However, when attempts have been made to measure the learning taking place following practical work, a rather pessimistic picture emerges (Johnson and McCallum, 1972; Johnstone and Wood, 1977; Gunning, 1978; Solomon, 1980). Tasker (1981) is not surprised that science teaching is not as effective as we might have thought. He found that in many science classrooms

1) pupils tend to consider each lesson as an isolated event while the teacher assumed that the pupils appreciated the connecting link between the lesson and the previous learning experiences,

2) pupils sometimes invented a purpose for the lesson which was subtly but significantly different from the purpose intended by the teacher,

3) pupils often showed little interest in, or concern about those features of an investigation which the teacher, or textbook writer, considered to be critical scientific design features,

4) pupils' knowledge structures, against which learning experiences were considered, were frequently not the structures the teacher assumed pupils had, and

5) pupils' understandings, developed from the outcomes of experimental work, were frequently not those that the teacher assumed were developed.

Tasker (1981) also found that pupils are more concerned with deciding what to do next in science experiments than in considering scientific concepts. Tasker's (1981) view of pupil practical work is supported by Johnstone and Wham (1982). Pupil concern with the physical tasks of the experiment may be the result of assessment procedures rewarding well-written laboratory accounts, but omitting credit for pupils' statements about how
they really view the procedures. Being critical about the students' "recipe type" approach may be unfair since this may be the inevitable result of the way in which practical work is frequently presented and organized by laboratory texts and curriculum guides. From the teacher's point of view the material may seem to be well explained and coherently organized. To the learner, the situation may look very different. The incoming information may have no apparent meaning as pupils could lack the conceptual structure to interpret this new information. Freyberg and Osborne (1981) point out that children often misinterpret the ideas that they are taught if they conflict with their own personal views. The willingness to construct meaning and test these against experience and structures in long term memory is critical in terms of developing learner-generated meanings. Pupils have to be motivated to construct new meaning for concepts since this often requires much mental effort. Motivation depends on individuals accepting a major responsibility for their own learning (Wittrock and Lumsdale, 1977).

Pupils often view practical work as an intellectual non event. "The teacher asks, 'I wonder if something will happen when we add A to B?'; the pupil thinks 'if nothing was going to happen, he wouldn't be doing it. Anyway he will tell us the answer at the end even if the experiment doesn't work!'" (Johnstone and Wham, 1982). Postman and Weingartner (1971) suggested that unless pupils perceive a problem to be a problem and what is to be learned to be worth learning, they will not become active and committed in their studies.
Another working hypothesis that has been advanced (Johnstone and Kellett, 1980; Johnstone, 1980) is that learning is severely hampered in a high information situation in which the working memory is overloaded with incoming data. The term working memory is used to describe the area of memory that is sorting and processing information into short term or long term memory. Posner (1982) also talks of a "problem space" and the facility of memory to create this space. "In many problems, setting up the problem space leads to the establishment of one or more goals to be achieved" (Posner, 1982). Planning takes place next and subgoals are determined and a priority system decides which subgoal is worked on first (Greeno, 1977). The problem solver thus plans work on a subgoal using previous experience with similar problems and his framework of the concept as an aid. The mental activity that pupils engage in to construct meaning and test constructions against sensed experience and structures in long term memory are the result of motivation. Motivation is closely tied to intentions, plans and previous experience and reflects more than momentary environmental stimulation. Attention to the practical task is influenced by aspects of long term memory and cognitive processes. Attention becomes selective due to these past experiences and therefore results in selective perception. Attention involves both attending to the unexpected and a sustained interest in the experience and requires voluntarily controlled effort (Wittrock, 1981).

In order to construct meaning from the sensory information provided by the experiment, links need to be generated to perceived relevant information in the long term memory. In the event that links are not generated between new information and information in long term memory the
learner is required to employ alternative strategies (Collins, Brown and Larkin, 1980). These include:

1) reconsidering tentative links and attempting to link alternative aspects of memory store to the sensory information,
2) considering the possibility that unfounded assumptions were used as a basis for attention and selective perception,
3) attempting to link different aspects of the sensory information to memory store, and
4) systematically considering all possible links to different aspects of long term memory in an attempt to construct meaning.

It is conceivable, however, that these alternative strategies could yield different views of the phenomena being studied. Although it may be plausible, as some have suggested, that children and scientists construct meaning in basically similar ways from their experiences, the views children generate are often very different to those of scientists. Osborne, Bell and Gilbert (1982) suggest a number of possible reasons for this:

a) Children tend to view things from a self-centred or human-centred point of view and tend to consider only those entities and constructs that follow directly from everyday experiences,

b) Children's experiences of the world are limited and tend not to include contrived experimental situations,

c) Children tend to be interested in particular explanations for specific events and tend not to be concerned with the need to have mutually coherent and non contradictory explanations for a variety of phenomena, and
d) The everyday use of language tends to be subtly different from the language of science, particularly with regard to basic and important words, like "animal", "friction", and "force", and these everyday meanings tend to shape children's constructions.

Research conducted to date suggests that children's ideas related to science concepts can remain unaltered since science teaching has not encouraged conceptual change. Children may have no real motivation to change their conceptions. Symington (1981) found that children who could provide their own reasoning for an everyday phenomenon tended not to be interested in what other pupils had to contribute as an explanation of that phenomenon - they already had an explanation that was perfectly satisfactory to them. An understanding of some aspects of current scientific thought would seem to require a major restructuring of children's earlier ideas. The student may choose to see a personal model as invalid and replace it with another model which could be that of the teacher or a fellow student. Sometimes the change if far from that envisaged by the teacher. Examples can be found where older children have ideas which appear less congruent with the views of scientists than the views of younger children (Osborne, 1981; Bell, 1981; Gunstone and White, 1981).

Tasker's (1981) findings concerning classroom experiences implied:
1) meanings are frequently generated by pupils which are substantially different to those hoped for by teacher, textbook writer, or curriculum developer,

2) lessons are not linked by pupils to the appropriate knowledge from
previous lessons,

3) pupils generate a purpose for a learning activity which is different to the teacher's intended purpose,

4) insufficient links are made, or are able to be made, to scientific patterns of thought in memory to ensure that full consideration is given to the critical design features of the experiment, and

5) the knowledge structures in long term memory used to generate meaning from a learning experience are sometimes inadequate, or inappropriate, and this leads to non scientific outcomes.

Freyberg and Osborne (1981) indicate that it is easy for pupils to make links to inappropriate aspects of knowledge in long term memory. Much of science practical work does not encourage the pupil to find links between knowledge in long term memory and incoming information, or to construct meaning and evaluate this meaning against their own experiences.

Teachers are unlikely to view laboratory work as obscure, meaningless, isolated events since they are able to construct meaningful links between the knowledge structures provided by the previous lesson and those concepts that are to be presented in the next lesson. It is more probable that teachers have considered the problems caused by detailed laboratory work and the amount of information that pupils have to deal with in the form of written instructions, verbal instructions, recall of manipulative skills, etc. More thought needs to be applied by teachers in the area of linking the incoming information to knowledge structures held by the pupil. This necessitates teachers knowing the substantive beliefs of the class and how the pupils are going to view the laboratory event and use the incoming information.
2.3 Educational implications

The beliefs that pupils bring to the science laboratory are often at variance with those that teachers wish them to hold. A transformation of these alternate viewpoints into viewpoints more acceptable to the science teacher often requires accommodation of new information. This change of viewpoint can be achieved using instructional strategies that promote conflict with the pupils' beliefs. Laboratory work is often used by teachers to promote concept learning, but as we have seen (Section 2.2), this is not always successful since practicals are often viewed as isolated events and links between the concepts they should provide and theory work are often not formed. Pupils often do not know how to solve some of the problems in experiments due to this poor linking of concepts or their lack of knowledge structures. Existing personal frameworks can therefore have a great influence on concept learning.

Preconceptions, alternative frameworks or children's science are all terms referring to a person's existing conceptual framework. They "are amazingly tenacious and resistant to extinction" (Ausubel et al., 1978) and can often interfere with intended learning outcomes. The student may understand new information differently from what was intended. This new information may well take be assimilated into the pupil's own framework but continue to be at variance with accepted scientific conceptions.

Teaching attempts to promote accommodation to new concepts. The term "accommodation" is taken from Piaget's (1964) theory to denote what happens in the student's mind as he modifies his preconceptions to reach consonance with the perceived data. Accommodation, then, requires
recognition by the learner of different views of concepts which cannot be readily accepted with their existing conceptions.

According to Hewson (1980), if children are to change their views they must first find their present conceptions unsatisfactory in some way. It seems that dissatisfaction with a present view is not an important enough reason for the pupil to change viewpoints. Children need an alternative idea to replace the present view and this is required to be 1) intelligible in that it appears coherent and internally consistent, 2) plausible in that it is reconcilable with other aspects of the child's view, and 3) fruitful in that it is preferable to the old viewpoint on the grounds of perceived harmony and usefulness (Hewson, 1980).

Any change in viewpoint may be a slow process since often scientists' views may appear to the pupil to be less intelligible, plausible, and fruitful than the pupil's own view (Osborne, Bell, and Gilbert, 1982). The less intelligible, plausible and fruitful view does not provide the motivation to generate the effort needed to construct meaning from new views and link them with ideas in memory that will develop a useful and sound understanding. Pupils need to feel that generating new meaning is worthwhile and successful. Often what is required in the learning of science is the restructuring of existing ideas so that pupils see things from a different framework. This personal restructuring has been likened to Kuhn's (1970) description of a major paradigm shift (Walters and Boldt, 1970). This may be achieved by showing pupils the inadequacies in their present conception and providing them with linkages and alternative frameworks which will help toward generating new and useful
ideas. New frameworks can simplify reality although they do not capture all that is going on.

2.31 Instructional strategies

It is important that the teacher understands both the scientists' views and children's views of a science concept. The teacher also needs to be able to assess whether or not a certain conceptual change is a reasonable teaching goal with a specific group of pupils. Tasks need to be provided so that a pupil may clarify their own view about the particular phenomenon under discussion. Pupils need the opportunity to debate the pros and cons of their existing frameworks with each other (Nussbaum and Novick, 1982). Nussbaum and Novick (1982) view the first phase in an instructional strategy for facilitating accommodation should be that of making every student aware of his/her own preconceptions. They suggest an "exposing event", a situation that evokes the student's own preconceptions. The "exposing event" should "naturally invite a student to explain it in terms of his own preconceptions". Explication of pupils' preconceptions involves developing an atmosphere which enables students to make explicit their own frameworks. Their productions might be verbal using class or small group techniques (Gilbert and Osborne, 1980; Nussbaum and Novick, 1981), in written form (Watts and Zylbersztajn, 1981), presented graphically (Pope, 1981), or some combination of these. Pupils should be encouraged to state their ideas clearly and concisely. This process encourages attention (Osborne and Wittrock, 1983) in that pupils are aroused to defend their own ideas and concentrate on relevant issues. The learning environment in which discussion takes place needs to be supportive and appreciative of the risk pupils take in disclosing personal
ideas. Where the scientist's view of a concept is not represented it may be appropriate for the teacher to introduce the scientific viewpoint as an alternative view. For the scientific view to be considered seriously it needs to be introduced in a way which takes into account the views pupils currently hold.

2.32 Laboratory work

If teachers examine the presentation of laboratory work they find methods that can be improved so as to aid the pupils' linking of concepts with new conceptual information. When we develop a general concept in lessons we often begin with a single idea and 'elaborate' it with examples. For practical work it seems that the reverse occurs - complex and numerous starting points lead to or obscure the main point we try to make. To reduce this problem we could adopt three ground rules: 1) Give a clear statement of the point of the experiment, 2) State clearly what is preliminary, peripheral, and preparatory, 3) Avoid possible overload of information by trying to teach manipulative or interpretive skills at the same time as data is being obtained.

Lawson (1983) suggests that without establishing a direct connection between hypothesis and experimental results, via predictions already based on explicitly stated hypotheses, the force of scientific experimentation as a means of generating knowledge is weakened. It is recommended that all experiments should be conducted and reported with not only a statement of hypotheses tested and results obtained, but with predictions generated as well. During the experiment the pupil can experience difficulty relating to the main point of the experiment and the relevance of incoming sensory information. When the pupil can "chunk" incoming information some
of it can be declared redundant and other preliminary and preparative work, such as labelling equipment and drawing tables for data, can be separated and organized accordingly. A variety of visual representations of information may enable the learner to process the information in the way he finds more appropriate.

Instructional material may be used to provide retrieval cues so that appropriate meaning is generated from the material. Teachers could provide advanced organizers and questions to direct thought with the student clarifying thought through summaries, perhaps pictorially (Buzan, 1974) e.g. in flow charts and alternative explanations. Rigney and Lutz (1976) found in chemistry that supplementary verbal description with graphic analogies resulted in better learning and more positive student attitudes than presenting only verbal descriptions. There is an aim to increase attention so to influence an increase in the learner's voluntary control. Written material may need carefully worded headings, sub headings, and focus questions to clarify the intent of the lesson. Attention can be influenced by the questions teachers ask pupils or learners ask themselves. Pupils can be taught to ask each other questions or ask themselves questions (Fraze and Swartz, 1975). Pupils need to be encouraged to develop or be explicity taught strategies to direct their own study.

2.33 Problem solving

Osborne and Wittrock (1983) believe that pupils find difficulty in beginning stages of solving a problem. Pupils appear to be unable to construct meaning from the problem statement or connect their constructed
meaning of the problem to their knowledge structures. This is either due
to lack of linkages or inadequate knowledge structures. Research into
problem solving does not appear to have discovered all that is going on in
the student's head. It seems that it is not very useful to think of
problem solving as a "single, uniform capability" and strategies devised
to attain a general problem solving skill "is practically hopeless at
this stage of our understanding" (Greeno, 1977, p. 17). Problem solving
appears to be highly content specific. Michael Polanyi (1967) points out
that much of human knowledge is "tacit" in that, under ordinary
conditions, it can be explicated in words. Perhaps this applies to the
skills of problem solving as Larkin (1979) explains:

"if these tacit processes remain unexplained, then, to help
a beginner learn, there is little one can do beyond providing
examples and practice, and hoping that the beginner will
somehow 'pick up' these unspecified skills. But if one can
begin to build explicit models for formerly tacit processes
then it becomes possible to teach these processes, either
directly or through appropriately selected practice and
example. In addition explicit models for tacit processes can
aid in identifying and remediating errors in the developing
skills of learners."

If we want to improve problem solving ability in schools we could begin by
analyzing the kinds of problems children are asked to solve.

Elkind (1972) takes the position that instruction in controlled
experimentation generally should not be introduced until adolescence. In
contrast Lawson and Wollman (1976) suggest a very gradual introduction and
continued reintroduction of lessons involving concrete materials and
activities to enable students to make comparisons and judgements. Wollman
(1977b) suggests that a variety of experiences providing situations to
develop a general procedure may be useful since research on memory
confirms the positive value of varying the contexts in which an idea
appears.

Setting up a controlled experiment requires the organization of many parts into a coordinated whole. Understanding the separate parts is not sufficient. Time is required for integration of the parts. Not only is time required (perhaps more time than we allot in class) but practice too. Teachers may be able to integrate the parts by organizing the practical experience so that probing questions and memory retrieval cues lead pupils to generate the kind of meaning we want them to generate. To create the basic notion of fairness students could be confronted by the question of the validity of their judgements (Wollman, 1977b). As a result it is hoped that pupils might retrieve ideas from long term memory in order to better understand and interpret this situation. Knowledge of inappropriate contexts which pupils are likely to retrieve for the construction of meaning is also important. Pupils' prior knowledge structures should be built on where possible and not ignored.

Stevens and Collins (1980) point out that good teaching requires the teacher to investigate student understandings and their deeper meanings. The teacher requires some idea of the likely knowledge structures in order to build on and modify pupils' ideas but at the same time to be generally sensitive to and supportive of pupils' ideas and reasoning processes.
CHAPTER THREE

3.0 Methods of study

3.1 Introduction

The recent publication of numerous research studies, with their focus on the learner's cognitive structure, represent a major shift in the role and status given to the learner in the educational process. By using quantitative or qualitative methodologies many of the researchers have explored the organization of scientific concepts in semantic memory. Those using a qualitative methodology issuing from the interpretive ethnographic paradigm have in the past received heavy criticism concerning their validity, ungeneralizability and subjectiveness. Power (1976) describes such studies as ideographic. In these studies students' conceptualizations are analyzed on their own accord without reference to "an externally defined system" (Driver and Easley, 1978). Clinical interviews and case studies are often in the ideographic tradition. Supporters of ideographic studies have moved towards personal, flexible, interview techniques (e.g. Pines, 1979; Pines et al., 1978) with loose analytical forms of conversation used to identify student perceptions and construct a conceptual inventory.

In contrast "nomothetic studies" assess students' understanding "in terms of the congruence of their responses with 'accepted' scientific ideas" (Driver and Easley, 1978). Since these methods are often quantifiable, Power (1976) sees them as a reflection of the agricultural-scientific paradigm. The nomothetical approach is also
characteristic of many researchers engaged in mapping cognitive structure (e.g. Deese, 1965; Shavelson, 1974; Preece, 1976) using various forms of word association techniques.

Considerable disagreement exists over the appropriateness of these two methodological stances. Different researchers value and trust the two approaches differently and the pursuant of one tends to reject the other. Debate concerning the two method types does not centre only on the relative advantages and disadvantages of qualitative and quantitative methods but also on the clash of methodological paradigms. As Rist (1977, p. 43) states "Ultimately, the issue is not research strategies per se. Rather the adherence to one paradigm as opposed to another predisposes one to view the world and the events within it in profoundly differing ways". Or as Roberts (1982) suggests - research is not a "direct inspection on reality". People have used different ways in order to put constructions on reality. It has been argued that paradigmatic characterizations influence constructions on reality. Pepper (1942) believes that understanding the different approaches used in interpreting reality is aided if one distinguishes between the four "adequate" world hypotheses of formism, mechanism, contextualism and organism. Linking the two "adequate" world hypotheses of contextualism and organism, which use qualitative data, does not resort to a rigid and fixed approach since the three analytical devices Pepper uses to describe and compare the world hypotheses provide different orientations for research. Paradigmatic characterizations, those of the qualitative methodology being phenomenological, inductive, holistic, subjective, process orientated and of a social anthropological world view, are based on two assumptions (Cook
and Reichardt, 1979). Firstly, it is assumed that a method type is irrevocably linked to a paradigm and secondly that the quantitative and qualitative paradigms are assumed to be rigid and fixed. Cook and Reichardt (1979) argue that these points should not be assumed. No discipline is entirely "pure" with respect to world hypotheses and the emphasis of the different hypotheses function when conducting research in the process of putting constructions on reality.

Broad research paradigms should not be the sole determinant of the choice of methods. The choice of research method should also depend on the demands of the research questions and the research situation at hand. Quantitative methods have been developed mostly for verification or confirming hypotheses whereas qualitative methods were purposely developed for the task of discovery and generating hypotheses. The emphasis of evaluation research has shifted away from the verification of presumed effects toward the discovery and elucidation of possible underlying structures influencing educational outcomes. Much of this evaluative research relies on qualitative methods.

The conduct of research is essentially aimed at developing an argument. In quantitative research argument rules and principles test the sufficiency of the data. Qualitative research is appraised on a parallel basis - the argument has to be made defensible. The rules and conventions that warrant our moves from data to conclusion can be termed "warrants" (Roberts, 1982). Establishing warrants appropriate for use in qualitative research has been problematical due to the complexity of the interaction which occurs in the events of Science Education. However, Peters, Hirst,
Sheffler and others have clarified what educational concepts mean in an educational situation while Stephen Toulmin's work helps with regard to constructs such as discovery and inquiry, which are used extensively in science education.

The linkage that exists between paradigm and method can usefully guide one's choice of research method, but the research situation is also an important factor. The social scientist of the "agricultural scientific" school (Power, 1976) criticizes the ideographic tradition claiming that groups or individuals studied only once with a total absence of control produce data of little scientific value (Campbell and Stanley, 1966). However, Campbell has since revised his position and acknowledges their usefulness in educational research (Easley, 1977). Although one of the strongest arguments against these ideographic studies is their lack of generalizability, Cronbach (1975) suggests that "we reverse our priorities because the observer is appraising practice in its normal setting and observing its effects in context".

3.11 Background to methods used in the study

Any research programme with aims to enhance teaching and learning in the classroom must have meaning and fill the needs of the involved practitioners. Recognizing this Parlett and Hamilton (1977) and Stake (1974) established classroom research with emphasis on what was going on in the educational setting where the needs of the participants are given prominences. A further shift has then been to pay more attention to the learner as the focus of the education process.
For the teacher to obtain useful insight into his pupils' present ideas, reliable techniques are required for both finding out about a person's conceptual structures and for representing them on paper. Several techniques have been used in attempts to probe the learner's structure of ideas:

1) Clinical interviews with individual pupils (Pines et al., 1978; Lybeck, 1979; Erickson, 1979),
2) Word association or word sorting tasks (Preece, 1978; Shavelson, 1974; Schaefer, 1979),
3) Learners writing definitions (Schaefer, 1979), and
4) Bipolar dimensions using semantic differential tests (Osgood et al., 1957) or repertory grids (Kelly, 1955).

In Sutton's (1980) review of research techniques for probing the organization of a learner's prior knowledge, he pointed to the limitations of some of these techniques when it comes to their use in the classroom as part of the science teacher's repertoire. Although the word association and word sorting tasks are quantifiable, there are problems with the infinite associations, randomness, and the lack of the nature of the relationship between words (Stewart, 1979). Writing definitions may prove too difficult for the pupils whilst selecting definitions, although quantifiable and easier, may still not provide the dynamic quality of thought. Using methods involving bipolar dimensions may not be useful in the classroom due to their application difficulties and the skills required in analysis.

As Fensham et al. (1981) point out, if research procedures were to
become part of the regular pattern of teaching and learning in science classroom they would have to meet a number of criteria focussed on issues such as:
1) the amount of instructional time required,
2) congruency with teacher behaviour,
3) providing tasks within the abilities of students and teachers,
4) teachers are able to use intellectual skills and procedures involved in data gathering and analysis,
5) analysis and data meeting the requirements of the teacher, and
6) learning will be helped as a result.

With many of the above criteria in mind and considering the teaching situation the clinical interview and other descriptive ethnographic techniques were used to collect some of the data for this study. These techniques will be described in more detail in the following two sections.

3.12 The clinical interview

The clinical interview as used in science education research is derived largely from Piaget's (1929) work and has been used extensively to find children's responses to a variety of physical phenomena. The interview has been defined as "a conversation directed to a definite purpose other than satisfaction in the conversation itself" (Bingham et al., 1959, p. 3). The purpose is fixed in the investigator's mind and if care is not taken may lead to the "situation of interviewer seeking information from interviewee, and at the other (end) a troubled interviewee seeking help from the interviewer" (Posner and Gertzog, 1982, p. 195).
The clinical interviewer's goal is to ascertain the nature and extent of an individual's knowledge about a particular topic area by identifying the relevant conceptions held and the relationships among those conceptions. In order to do this, questions are used to elicit information and encourage the pupil to take the lead and talk more freely. "The art of questioning, does not confine itself to superficial observations, but aims at capturing what is hidden behind the immediate appearance of things" (Piaget, 1926, pp. xiii-xiv).

Pines et al. (1978) have produced much work using clinical interview techniques. It is pointed out that the researcher has to deal with two aspects of the interview. Pines sees these as being the inflexible and flexible parts. The inflexible parts are as follows:
1) establishing rapport,
2) setting the scene of the interview including the arrangement for recording, and
3) declaring of the content field by the researcher and its acknowledgement by the learner.

The flexible part involves the interviewer's judgement as to how much to encourage pupils with unbiased 'I see', 'Go on', 'And so' statements before refocusing the learner on the original conception. Eliciting these original conceptions is achieved by semi-structured question framework. This framework is made up of questions that are general enough to be placed in a variety of places within the interview. The questions open-ended nature should encourage the child to respond freely in his own words therefore revealing the nature of their perspective. If the answers are judged irrelevant the question may be asked again in another form (Pines
et al., 1978). Conversations overcome the reluctance on the part of the subjects to respond fully in writing to questions. However, there are difficulties in obtaining qualitative data using the interview. The interviewer has to realize the danger of allowing his preconceived ideas to lead to suggestions that the student may take up, thereby obtaining misleading data on the child's genuine ideas. Nuances in phrasing, a particular word, or the selection and ordering of queries can all stimulate suggested convictions. After the interview, transcripts are made from the recorded interviews and these become the basis for later analysis.

3.13 Classroom data

The classroom teaching situation has more potential to distort the students' responses toward a more 'accepted' school view of the topic area under consideration than the clinical interview setting. This is because the classroom is seen as an assessment environment. Hence classroom based research has always been faced with a number of difficult methodological problems regarding the validity of the data collected. Douglas Barnes (1979) has suggested an approach that may alleviate some of these difficulties and be more manageable to handle in the classroom. After working with different small groups of pupils on a variety of topics he concluded that small group work allows discussion, recording of experiences with speech being used to communicate or reflect thoughts. Gagne and Smith (1962) have also indicated their support for student verbalization for clarifying their ideas.

Barnes (1979) found that pupils tend to organize thoughts on a
clearer basis for fellow pupils than they do for teachers. This seems dependent on the knowledge of the audience; the less knowledge the audience is expected to have then the more explicit the explanation. He also found that taped discussions of children working on their own on a problem that had been clearly defined produced transcripts with examples of "exploratory speech". The talking out of problems, rearranging of ideas and tentative moves towards hypotheses were seen as relevant to the pupil. Occasionally the interviewer in the clinical setting may perceive something as irrelevant whereas the student sees these ideas as important to his "framework". Groupwork may be a safety net to catch these ideas. Once children have become used to explaining their groupwork to a tape recorder the "exploratory speech" may reflect more of the nature of the children's ideas than would a more formal setting, such as an interview or a large class discussion, which would normally produce a "formal" response.

In many examples shown by Barnes and Todd (1975) the pupils discussed questions posed on a task card. The task had been clearly explained, pupils had been introduced to the equipment and shown how to operate it. These researchers were anxious to preserve in their analysis of the resulting conversations the features of children's talk that they viewed as theoretically important, i.e. the construction of the pupil's own knowledge would be conserved. This is essential since the structuring of concepts is thought to be an ever changing, dynamic framework.
3.2 Methods of data collection

The methods of data collection used in this study were selected because they could be accomplished within a normal teaching situation. Pupils did not need to learn new skills and a learning situation was created by these methods.

Clinical interviews with individual pupils and transcripts from children's group work experiments have been used to identify the beliefs concerning bacteria and the interaction of these beliefs during experimental procedures. Group work tapes have also been used, although less rigorously, along with written work.

3.21 Data collection schedule

The collection of data was organized to fit into the normal school timetable. Science lessons were available within the time limitations of the curriculum. These consisted of one seventy minute lesson and, two days later, one thirty-five minute lesson per week. It was also possible to use a thirty-five minute library period that ran concurrently to the single science period. When pupils were interviewed during this time they were provided with a word search task on "diseases" and after being interviewed they returned to the library.

The clinical interview to obtain the pupils' beliefs concerning bacteria (interview one) took place prior to the introduction of the topic in the first half of the second school term. This involved thirty-one pupils.
In the second half of the term the topic of "bacteria" was introduced using the two experiments in the study. Due to curriculum constraints a maximum of three weeks was allowed for this topic so tasks and interviews were arranged for the two experiments within this time span. Clinical interview two involved nine individual pupils while two groups of four and three pupils respectively provided tapes of group work for the experiment 'Bacteria in the Air'. Clinical interview three involved another nine pupils and two more groups of two and three pupils respectively were taped performing the experiment 'Bacteria on Ourselves'.

TABLE I Summary of data gathering schedule for experiment one

"Bacteria in the air"

<table>
<thead>
<tr>
<th>Time</th>
<th>Class period 1</th>
<th>Between class</th>
<th>Class period 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task</td>
<td>set up experiment 'Bacteria in the air'</td>
<td>individual clinical interviews (interview 2) (9 pupils)</td>
<td>group discussion of experiment</td>
</tr>
<tr>
<td>Data Gathering Method</td>
<td>small groups taped during experiment</td>
<td></td>
<td>small group discussions</td>
</tr>
<tr>
<td></td>
<td>Group 1 A (4 pupils)</td>
<td></td>
<td>presentation of overhead</td>
</tr>
<tr>
<td></td>
<td>Group 1 B (3 pupils)</td>
<td></td>
<td>materials</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>laboratory write up</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>centred on specific</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>questions</td>
</tr>
</tbody>
</table>
### TABLE II

**Summary of data gathering schedule for experiment two**

"Bacteria on Ourselves"

<table>
<thead>
<tr>
<th>Time</th>
<th>Class period 3</th>
<th>Between class</th>
<th>Class period 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task</td>
<td>set up experiment</td>
<td></td>
<td>group discussion of experiment</td>
</tr>
<tr>
<td></td>
<td>'Bacteria on Ourselves'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data</td>
<td>small groups taped</td>
<td>individual clinical</td>
<td>small group discussions</td>
</tr>
<tr>
<td>Gathering Method</td>
<td>during experiment</td>
<td>interviews (interview 3)</td>
<td>presentation of overhead materials</td>
</tr>
<tr>
<td></td>
<td>Group 2 A (2 pupils)</td>
<td>(9 pupils)</td>
<td>laboratory write up centred on specific questions</td>
</tr>
<tr>
<td></td>
<td>Group 2 B (3 pupils)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 3.3 Description of the clinical interviews

Each pupil's ideas were recorded on tape for the first initial interview. Whilst every pupil willingly participated in the interviews, the researcher felt that the goodwill of the pupils would be put to the test if each pupil was interviewed for each experiment and timewise this was prohibitive. Thus for both experiments one and two nine pupils were interviewed.

Pupils were asked for permission to record their conversations. Each interview was intended to be as relaxing as possible and it was stressed that in essence it was a private interview and a non-assessment situation. Each interview lasted approximately ten minutes.

**Clinical Interview One**

The purpose of this interview was to elicit the pupils' beliefs about
bacteria. Pupils were interviewed prior to any school learning experience concerning bacteria. The interview was structured around a series of questions intended to elicit student beliefs. In this first set of interviews the typical questions asked were:

1) Have you ever been ill?
2) What kind of things cause these illnesses?
3) How do people catch these illnesses?
4) Are bacteria/germs alive?
5) How can you tell?
6) (If so) where would they live?
7) What do bacteria/germs look like?
8) Do you think all bacteria/germs are harmful?

Clinical Interview Two

The purpose of this interview was to elicit the understanding of the experiment and its results, 'Bacteria in the air' (Experiment 1). The class carried out the experiment in small groups after the researcher had explained the procedure and shown the petri dish and the agar to the class. Pupils were asked to think about the questions reproduced from the Combined Science text and answer these for homework.

A few days later, before the next lesson and after some growth had been achieved on the plates, nine pupils were interviewed. The interview was structured around the questions considered for homework but in a less formal manner. The following questions are typical of an interview at this stage:
1) Why did we sterilize the agar?
2) How could we tell that there aren't any germs in the jelly when we started?
3) Why did we have clean hands at the start of the experiment?
4) Why did we have a plate for a draughty place (plate 1) and a draughtless place (plate 2)?
5) Why did we have to open the dishes for so long?

Clinical Interview Three

The purpose of this interview was to elicit the understanding of the experiment and its results, 'Bacteria on Ourselves' (Experiment 2). The whole class carried out the experiment according to instructions reproduced from the Combined Science Text. Again the pupils worked in small groups and afterwards considered questions concerning the method of the experiment. These questions formed the basis of the the third clinical interview. Nine pupils were interviewed; the following questions are typical of an interview:
1) Why do you think we had plates A and B?
2) What do you expect to see on these plates?
3) If there weren't bacteria on plate C what was the purpose of having plate C?
4) Does it really matter that all the plates were sterile at the beginning of the experiment?
5) Why did we put plates in the incubator?

3.3.1 Description of the taped small group discussions

The taped small group discussions involved four groups of pupils in
total. Two groups of pupils were selected for each experiment. Twelve pupils were involved in this part of the project.

Each group was provided with a work sheet explaining the procedure for the experiment and a question sheet for the group to answer. The groups were shown how to use the tape recorder and asked to record their work as soon as they got to their desks. Each group worked in a separate room until they felt that they had set up the experiments and answered the questions satisfactorily.

Small group work (1A and 1B) during class period 1

Pupils were selected so as to be representative of the class. For this experiment "Bacteria in the Air" group A consisted of four boys. Originally only three boys were in the group but a new boy came late to class and social considerations dictated that he joined this group. Group B consisted of three girls. The members of both groups were all used to working with each other and were cooperative and able to work on their own with minimal supervision. The pupils were also considered to be sympathetic with the project and enjoyed taping their ideas.

The groups' task was set out on a printed sheet and they were asked to record the setting up of the experiment and discuss and answer six questions on an acetate overhead projector sheet (See Appendix E for a description of these instructions and questions).

Small group work (2A and 2B) during class period 3

Two more groups were selected to participate in the taping of
experiment two "Bacteria on Ourselves". Group A consisted of two girls; their third member of the class being absent. Group B was made up of three boys. Again the group task was set out on a printed sheet, tape recorders were provided along with equipment for the experiment. After setting up the experiment the pupils were asked to discuss their answers to seven questions and also record these answers on an overhead projector acetate (See Appendix E for a description of these instructions and questions).

Other group work

During class periods two and four the pupils worked in their original groups and a spokesperson for each group presented the group's ideas and answers to the questions answered in the previous lesson. Each group produced an overhead for this purpose.

3.32 Written work

The written work produced was of two types, 1) as a result of group discussion, or 2) write ups from laboratory experiments with questions. The questions used in each case were given to pupils for consideration as a group and for homework.

3.4 The subjects

The subjects used in the study were of the same age group that the curriculum developers of the Nuffield Combined Science Scheme had in mind when writing the section on microbes. The pupils attend a secondary modern school in a suburban environment. All of the class were considered
to be in the second quartile of the school population for IQ scores. The
class consisted of thirty-one twelve/thirteen year olds who already had
been taught Science as a group for one term by the researcher. This class
was chosen for the research project since they were responsive and
enthusiastic and it was considered that they would benefit from the
research approach taken. None of the pupils had had any formal teaching
concerning microbes. In the first term all had learnt to use microscopes
and taught some basic concepts of cells. Their first year curriculum
had included work on living things.

All the members of the class were involved in the first clinical
interview. In the second and third interviews approximately one third of
the class was used in each case. Pupils selected for group work made up
the third portion of the class. The schedule is summarized below:

| TABLE III | Number of pupils involved in interviews |
|---|---|---|
| clinical interview | 1st | 2nd (1st experiment) | 3rd (2nd experiment) |
| number of pupils | 31 | 9 | 9 |
| groupwork | 7 | 5 |

For the group work pupils were selected on their ability to work without
help, in a group, with a willingness to discuss and listen to other
pupil's views. This was essential in order to obtain some sort of
interaction of ideas. The prior selection of these pupils left two thirds
of the class available for other interviews. Interviews took place in a
normal school setting and they were used as a learning situation for the
pupils.
3.5 Analysis of data

3.5.1 Introduction

As already mentioned earlier in Section 3.12, various methods have been used in the past to represent a subject's knowledge. Deese (1965) was among the first to investigate cognitive structure using word association tasks that provided quantifiable data which could be used to construct concept maps. Researchers (Deese, 1965; and Shavelson, 1974) interpreted the pattern of interconnections among associations as being a major aspect of cognitive structure. Shavelson (1974) has stressed the importance of examining an hypothesized structure or organization of concepts in a subject's memory and its possible relationship with subject matter. He attempted to determine this hypothesized mental structure using word association and represented these in diagraph form and spatial maps. These assessment techniques assumed that the response retrieval from long term memory reflects part of the structure within and between concepts. However, a major problem with associative mapping techniques is that concepts learnt at the same time may only be associated in temporal terms. The researcher needs to make sure that the assessment technique does in fact test cognitive structure. Sutton (1980) also has reservations concerning mapping since this suggests a lack of fluidity in mental structure. However, Preece (1978) suggests that concept maps only describe the format of the data base. In science learning the links between concepts are precise propositional statements that have very definite meaning. Scientific concepts have a multiple of private meanings which change or extend their meanings. Stewart (1979) argues that associative mapping procedures do not allow this flexibility.
The human information processing view directs its efforts towards the development of theoretical models of how knowledge might be stored in a propositional format. Many different assessment techniques have been used to acquire information. Of the many, clinical interviews provide researchers with the opportunity to gain insights into how people store and recall knowledge and use it in thinking. However, care should be taken in the clinical interview situation by the researcher to make sure that he/she is pursuing the line of thought of the subject and not his/her own.

During analysis of data derived from the clinical interview there is a danger in the possible misinterpretation of responses. Piaget suggests that "the psychologist must in fact make up for the uncertainties in the method of interrogation by sharpening the subtleties of interpretation" (1929, p. 9).

Rowell (1978) used clinical interviewing as the principal technique for evaluating concept learning and evaluated each child's interview responses by categorizing his or her overall performance. The outcome was one response rating per child which characterized the degree of the child's use of models. Movement toward characterizing a particular child as a "modeler", "partial modeler" or "non modeler" has obscured the capability for describing the substantive qualities and interrelationships of the concepts being learnt. According to Posner and Gertzog (1982), Rowell failed to establish a useful or valid measure of concept learning.

Another study of science concept learning was carried out by Pines
(1977) using a modified Piagetian clinical interview. Pines disagreed with categorizing children since they "exhibit responses characteristic of many categories irrespective of the category system used" (1977, p. 192). In his analysis he attempted to reduce the interviewee's discourse to manageable units while at the same time preserving its integrity. This system of "conceptual propositional analysis" (CPA) was designed to elucidate "substantive content, indicating cognitive differentiation and enabling the comparison of discourse analysis" (Pines, 1977, p. 74). The CPA process could act to increase the danger of failing to recognize suggested convictions by including in children's responses phrases taken directly from the investigator's questions. Although the basic sense of the discourse is maintained, the origins of certain concepts and association become unclear.

3.52 Analysis used in the study

As mentioned in Section 2.21 the concept map is a device to explicitly represent a number of concepts, they can also be used to determine the framework of pupil beliefs toward this subject matter. Concept maps have application in the teaching of all sciences at all levels and can provide the teacher with much valuable information. A concept, then, is a set of relations among other concepts. The quality of the concept is due to the relations with other concepts. The map illustrates the data base present in the pupil's long term memory (Preece, 1978) and the propositional relations between the concepts at that one particular time. The terms in the boxes are concepts and the verb or logical connective constitutes a proposition. "The nature of a person's understanding of a concept changes as it is associated with a wider array of concepts and specific
propositions" (Malone and Dekkers, 1984). Based on Ausubelian (1978) learning theory it would be anticipated that concept maps demonstrating meaningful learning would possess an organization of concept differentiation ranging from the most general, more inclusive concepts at the centre to more specific and less inclusive concepts at the perimeter. Examples of pupils' concept maps are shown in Appendix A2.

Pupil's propositional statements extracted directly from the first clinical interview data were used in the construction of the concept map for that pupil. Using these propositional statements, and with the aid of the concept maps constructed from them, the substantive beliefs held by the class concerning bacteria were obtained and summarized.

In order to detect the beliefs pupils held concerning the two experiments being studied propositional statements supplied by the interviewed pupils were again isolated. These were also used to compare with the substantive beliefs obtained from the first interviews in order to detect any general conceptual change. It was felt necessary to extract statements from the interviews as close to the original pupil statements as possible since it was thought essential to capture the subtle meanings of each statement. Although concept maps were used in the first instance to isolate substantive beliefs it was thought that the propositional links between concepts provided in the interview were not static and showed signs of flexibility that a concept map could not display. To lend support to interview data extracts from group work and written work were also used.
CHAPTER FOUR

4.0 Introduction

This study has been conducted with the knowledge that the prior beliefs which pupils take into the science laboratory interplay with their understanding of the scientific processes of experiments, or as Finley (1983) suggests that the concepts "drive" the scientific processes. By this statement Finley means that the exact nature of science processes are dependent upon the conceptual knowledge that is used to understand a particular phenomena. In order to examine the way in which pupils' beliefs concerning bacteria interact with their understanding of the experimental procedures involved in the two experiments studied, it was, firstly, necessary to extract the substantive beliefs pupils held concerning bacteria from the first clinical interview. As an aid to analysis, concept maps were constructed for the elicited beliefs obtained from individual pupils. The next step involved extracting pupils' viewpoints relating to specific aspects of the experimental setting from clinical interviews two and three. The three clinical interviews conducted provided data for the following research questions:

1) What methods of identification of bacteria are used?
2) Are bacteria viewed as living units and if so, why?
3) Is it important to have sterile media and if so, why?
4) Is it important to have a control in the experiment and if so, why?
5) What is the overall understanding of the experimental procedures elicited from the pupils?
This chapter presents answers to these research questions.

The material extracted from the transcripts is true to the pupils' recorded speech. The nature of this pupil speech is truncated and hesitant and in many cases the sentence construction is incomplete due to pupils reflecting on their argument and then starting a new line of thought. Where appropriate, the missing words have been added in parentheses to help the reader understand the text. The author views the original transcript material as an important data source since it provides opportunity for closer inspection of the nature of the pupils' thinking. Written material provided by the pupil is not able to reveal the nature of pupils' thinking in such detail.

Due to the vast amount of data collected, it was not feasible to reproduce all utterances made by the pupils. Selected parts of transcripts have been used in the following sections as illustrative material of substantive beliefs held by a number of pupils or of unique viewpoints held that are particularly interesting. Selected complete transcripts for all data gathering methods can be viewed in the appendices.

4.1 Pupils' substantive beliefs concerning bacteria

The following substantive beliefs were obtained from transcripts of the initial clinical interview. This first interview involved thirty-one pupils in the second year class (12-13 year olds) being taught by the interviewer at the time.
In the class of thirty-one pupils, eleven pupils provided spontaneous convictions that bacteria cause many diseases. Thirteen pupils used the word "germs" while three pupils used both germs and bacteria and indicated that the word germs was a general term that included bacteria. Two pupils used the word germs to include the group they knew as viruses. Only one pupil used the colloquialism "bugs". All, except one pupil, related the belief that diseases were caused by bacteria, germs or "bugs". However, in the class there were ideas that environmental circumstances e.g. getting cold, cold weather and water, washing hair and going out would cause a cold. Eight pupils concurred with these beliefs but only one believed that personal habits and environmental factors as mentioned were the only causal agents of disease.

Bacteria or germs were considered small and could only be seen with the aid of a microscope (24 pupils) and they were small and light, usually floating in the air (10 pupils). Nineteen pupils believed that diseases were spread by breathing in these bacteria and germs either from someone else or from the air; of these, ten pupils identified sneezing or coughing as mechanisms that spread disease. Fifteen pupils said that they thought that different types of germs or bacteria cause different diseases. In the following excerpt, Sharon and Mark give their reasoning for this idea:

Int: How come there is such a difference between colds?
Sharon: Types of germs.
Int: How could you tell they were different types?
Sharon: They react to different parts of your body.

Int: Do you think there are lots of different types of germs around?
Mark: Yes.
Int: How do you know? (that there are different types of germs around)
Mark: Because there are loads of diseases you catch. A different germ for every different disease.
Apart from bacteria or germs causing a variety of different ailments they were different in shape (8 pupils), size (4 pupils), and complexity of appearance (1 pupil). All pupils with ideas about germs or bacteria thought they were living although the reasoning behind this was not too coherent. Only two pupils identified three activities of living organisms, but they didn't use these as their reasons for bacteria being living as can be seen in the following extract:

Int: What makes you think they are living?  
Sharon: Because they form plaque in your teeth and ....  
Int: But you're always brushing away this plaque, don't these bacteria disappear?  
Sharon: Yes, but they must be alive because they come back all the time.

Sharon mentioned that bacteria can grow and become "bigger like families do, you know they were reproducing and that", and, in her words, also "eat cells". However, these beliefs were not given as reasons for the organism to be considered living.

Other pupils appear to be able to discuss the attributes of "living things" better than the characteristics of live microorganisms:

Int: How do you know that they are living?  
Deborah: I don't know, (I) think they do.  
Int: What kind of things do "living things" do?  
Deborah: They eat.  
Int: So what would a virus eat?  
Deborah: Blood cells.  
Int: So they live in the blood, do they?  
Deborah: Yes.  
Int: If there is only one virus in your body it won't do you much harm will it?  
Deborah: No, they can multiply though.

Int: How would you know that things are living or not?  
Mark: If they move around they are probably living.  
Int: Are there any other reasons?  
Mark: They eat and drink.
Many students used other reasons not related to the normal characteristics attributed to living organisms. For example:

Int: How would you know whether they (bacteria) were alive?
Philip: Because they wouldn't know where to go else, would they - in your teeth and your throat and that.

Int: How do you know they (bacteria) are living?
Clive: They've got to be haven't they.
Int: Well no - there are lots of things that are dead.
Clive: Well if they were dead they wouldn't be causing any illnesses because you get different germs inside you that kill them so you don't get the disease.

Int: So how would you know that they (bacteria) were living?
Justine: Because if they weren't you wouldn't have the disease else and they would be dead and wouldn't be able to get inside you anyway.

The belief that bacteria or germs were living because they caused a disease was held by five pupils.

There was a range of locations where one might find bacteria; in the air (ten pupils), in animals' bodies (nine pupils), everywhere (seven pupils), in the earth or dirt (three pupils), on skin (three pupils), in water (three pupils), in blood (two pupils), and in cold places (one pupil). Only two pupils thought that bacteria required a living host.

There was a lot of optimism that these bacteria could be killed and even might be useful when dead for making medicines or vaccinations. When alive good germs fight off bad germs and these same germs could also be used for testing against other germs. Nine pupils mentioned that the body had a defense system against such pathogens as bacteria and a few talked about immunity (two pupils), antibodies (one pupil) and antibiotics (one pupil).
In summary, many pupils had a wide range of beliefs concerning microorganisms that caused disease. Pupils expressed most of their information about bacteria through their beliefs of disease. A surprisingly high proportion of the class used the term bacteria whilst others were more familiar with the term "germ". Both words were associated with organisms that are small and living. However, life concepts throughout the class were mostly unsupported by other concepts. Bacteria and germs were considered to be quite common organisms easily passed on through the air by people sneezing and coughing and they were often considered alive because they could cause disease. People often were thought to become ill through contact with water and bacteria had some role to play in this belief. It was reassuring to note that many of the pupils believed that these bacteria caused short term illnesses and that the body had some mechanism of fighting disease.

Each pupil viewed the relationships between their concepts of bacteria/germs in a slightly different and unique way. So as to provide an overview of each pupil's beliefs and their relationship to one another a concept map was constructed from substantive beliefs taken from each pupil's first clinical interview. The linkages do not indicate the strength of the relationship but simply that one exists and that this relationship was expressed by the pupil. Appendix A2 provides examples of this type of annotation of pupil responses.

4.11 Pupils' sources of information

In the previous section the variety of substantive beliefs elicited
from the first clinical interview were discussed without reference to the pupils' sources of information. From the multiformity of beliefs shown there could be a variety of information sources. It is to these sources that this section is addressed.

Pupil's vocabulary often reflects the nature of the source of information. Television documentaries use the word bacteria rather than germ and could influence the pupils to use the word bacteria. Three pupils related information that they obtained from watching television programs, but apart from programs pupils view advertisements that provide information regarding "germs" and hygiene. Some of the pupils who used the word bacteria had watched T.V. documentaries, one had even viewed the plating of cultures as the following excerpt shows:

Mark: I watched a program on television where they got this jelly stuff and they smeared one, they smeared a mumps smear over it and then they got something out of this bloke's body and smeared it on top of it to see what happened and all the germs from the mumps had split up into little groups so the bit that they put on top had spread out with it and the mumps germs were sort of shrinking and getting smaller.

These events have the potential for modifying frameworks or even in Lewis's case, extending them:

Lewis: Sometimes they've (doctors) got the dead disease and they inject into you so you can get white corpuscles and things like that to fight it (bacteria).
Int: Where did you learn about white corpuscles?
Lewis: I watched a program on telly.

Others had had discussions with respected authorities such as dentists. It is possible that dentists could influence pupils' conceptual frameworks by providing additional information about bacteria. This would be in addition to sources from television and books. An extract from
Philip's interview shows the concepts he gained from a visit to the dentist:

Int: What happens to bacteria and your teeth?
Philip: Umm... it gets in your teeth and they rot away.

Religious education classes at school provided more information about bacteria for Sharon:

Sharon: I know in R.E. we did about Lepers. Um, just means the conditions where you catch it and the way you live.

Apart from this sort of conceptual input from professionals and the media, the pupils also gained beliefs from their own experiences of illness. Although many believed living organisms were causal factors of disease, it was also apparent that many took note of "folklore" that stress the value of keeping warm, not getting wet feet, not going out with wet hair, or getting dirty. Neil and Mark provided views of this type in their interviews:

Neil: I went swimming and I didn't dry my hair properly and I got it (a cold) that way. I've got a bit of a cold all the time because I've got asthma.

Anthony: Well if you were dressed up and you didn't get wet you wouldn't get a cold.

Pupils who have produced quite detailed frameworks of beliefs have done so by recounting stories of their own illnesses and what they have observed on the television. A few talked of the value of medicines and vaccinations and how the body copes with disease with knowledge more likely to have been gained from documentaries and books than their doctor. Examples of this are shown in the following interview extracts:
Robert: Um, if you have an antibiotic it usually gives you a very small amount of the germ that you've got, just enough so that your white blood cells can fight back and get used to fighting them.

Lee: I think the white blood cells become stronger than the germs and that they eventually take over from them and the next time you get the disease it doesn't last long because the germs, no not the germs, the blood cells know how to fight it.

It is a possibility that pupils have already built complex conceptual frameworks concerning germs or bacteria from many sources. The pupil has not come to class with blank minds, he/she has already acquired beliefs concerning bacteria from many possible sources. How the beliefs making up conceptual frameworks interplay with the experiments investigated is analyzed in the following sections.
4.2 Pupils' beliefs elicited from Clinical Interview Two

The second interview took place after the pupils had set up the experiment "Bacteria in the Air" in their practical groups. The interview was conducted before the next lesson when colonies of bacteria were observable on the agar plates. This section presents the results to the research questions pertaining to:

a) pupils' identification of bacteria,
b) pupils' views of bacteria as living units,
c) the significance of sterile equipment and medium, and
d) the significance of the control plate.

4.21 Pupils' identification of bacteria

All pupils who were interviewed identified bacterial colonies on their agar plates and recognized that there were different types of bacteria on the agar. This notion was supported by the belief that different bacteria would have different colours. Only one pupil used the idea of shape to distinguish between bacteria but realized that the naked eye could not use this characteristic and the microscope would be needed. A third of the pupils mentioned the colonial nature of the bacterial growths and appreciated the great number of bacteria present in a small colony. Two pupils commented on the size of the colonies and gave explanations as to why the colonies varied in size. Steven appreciated the relative differences in size between the colonies and justified his statement with an argument that the bacteria had a different rate of division. This concept was held in the preliminary interviews. Excerpts from both interviews are included:
Clinical Interview One:

Steven: It (the bacteria) divides every twenty minutes doesn't it? It makes two more so in an hour you've got two, four, eight.

Clinical Interview Two:

Steven: I think it (size of colony) depends on how quickly they divide or it could be the bacteria in the air and how much there is of each.

In summary, pupils were as adept at identifying different types of bacteria as one would expect from within the limitations of the experiment. Few extended the opportunity for observation by suggesting looking at the shapes of individual bacteria with a microscope. The concept of the colony was only at the descriptive level and few could explain why the sizes of the colonies varied. This lack of explanation may be due to their concepts of life and the characteristics of living units. We now turn our attention to the beliefs pupils have about bacteria as living units.

4.22 Bacteria as living units

The pupils' beliefs concerning the life functions of bacteria were revealed in their responses to two questions. The questions were:

1) What is the significance of the sterile equipment and medium? and
2) What is the significance of the control plate?

Typical pupil responses of how the experimental procedures can be interpreted in terms of the life functions of bacteria are provided in the following two sub-sections.

Pupil significance of sterile equipment and medium

All the pupils interviewed argued that it was important that the agar
medium and in some cases the glass petri dishes (plates) should be sterile and that the potential source of contamination was mostly from the air. Nicole provides a response that is typical of the type of arguments used:

Nicole: If it (the agar) wasn't clean you wouldn't have the bacteria that you wanted because you'd already have something from the air when you open them before they came out of the pressure cooker.

Only three of the pupils mentioned the possibility of bacteria being present on the unsterilized glass plates and only two pupils out of the ten interviewed for this experiment suggested that contamination may occur from the agar itself, although one would have thought the agar appears more likely to be viewed as a food source for bacteria than the glass. For most pupils the main reason for having performed the sterilization procedure was to obtain a particular type of germ - i.e. the airborne bacteria. The other bacteria are the wrong sort as Jane confirms in her interview:

Jane: There may be bacteria on the dishes before we started and they might be the wrong sort of bacteria that we wanted on the dishes.

There was general agreement as to the importance of sterilization and the source of contamination from the air. Bacteria are mostly viewed as disease causing organisms living in some type of host. It must seem unusual to pupils that bacteria can be grown on agar in petri dishes. The bacteria are likely to appear on the agar later on in the experiment although how this occurs is not well understood. The relationship between the bacteria and the glass dish is such that the bacteria may be on the glass but not be a contaminant since pupils view them as inconsequential. Bacteria are acknowledged to be on the glass but not living. Philip's
transcript demonstrates this notion although later he expands upon his position.

Int: Are you saying that the control told us how clean the jelly was when we put it in?
Philip: Yes
Int: O.K. would it tell you anything else? Would it tell you how clean the glass plates are?
Philip: No, you didn't really want to know that we want to know about bacteria in the jelly.

Philip's initial concepts show him to believe that bacteria cause disease and that they are passed on through the air. In his first interview he stated that bacteria live inside living structures e.g. teeth and the throat. This appeared to be, for him, a requirement for them to live and multiply. In this instance he suggests that bacteria could be on the agar jelly, but he doesn't view any bacteria on the glassware as being important. This suggests that he does not believe that the bacteria are living and multiplying in these environments. However, he appreciates the sterilization procedure: "... if you didn't (sterilize the plates) the control would be the same as the others".

Sterilization of the equipment is viewed as an important procedure, but students do not verify if the procedure was successful or devise a way to check if there are any bacteria in the agar at the beginning of the experiment. The following excerpts from transcripts show this:

Question: How could we tell that there aren't any germs in that jelly when we started?
Nicole: Because they were cleaned.
Int: How do I know that they are absolutely clean?
Nicole: Could have looked down at them under a microscope to make sure that there were no germs.
Steven: If you put it in the pressure cooker it is bound to get rid of the bacteria because of the steam and the pressure.

It appears that although pupils accept the idea of airborne bacteria contaminating the agar resulting in colonies of bacteria at the end of the experiment, only a few appreciated other sources of contamination such as the glassware or the agar. Most revert to looking for physical signs of contamination, which are unavailable, at the start of the experiment to confirm these sources of contamination. The time element i.e. waiting for the contaminant bacterial colonies to grow in the sealed plate proves to be problematic as these excerpts suggest:

Question: How could we tell that there aren't any germs in that jelly when we started?

Chris: Well it (the agar) would be really clear. Put it under a microscope, put some under it.

(later): But if you left it (plate 4) it would do what these (plates 1, 2, 3) have done.

Michelle: Cause they were sterilized first and, er, you'd probably see the germs like cause now its come out all blotchy and that.

Andrew: They were sterilized.
Int: How do you know that the sterilization worked?
Andrew: Well it didn't leave any marks.

Andrew seems to believe that bacteria will grow on the glass in time but does not relate this idea of growth to what could happen in the agar.

The following transcript passage reveals this idea:

Int: Could we tell if the bacteria were in the jelly before we started?
Andrew: ..... I don't know that.....
Int: Could we tell there were bacteria on the glass before we started?
Andrew: No, I don't think so, it depends on how long they've been there if they're there for quite long they'd be noticeable.
As seen in the earlier transcript provided by Philip it was thought unnecessary to check for bacteria on the glass plates. He was able to reason why the bacteria on plates 1, 2, and 3 came from the air and why the jelly didn't possess contaminants before inoculation. He argues:

"Because they've been put in the pressure cooker for fifteen minutes so they must have been clean". "Because number 4 hasn't got any bacteria in and the other three has" and " if you didn't (have the agar sterile at the beginning) the control would be the same as the others."

Other pupils were unable to include in their frameworks that contamination of the plate may come from the glassware or agar itself and looked for other sources. These were again related to bacteria being in us and being breathed out as was the explanation in the first clinical interview for pathogens.

Nicole: Er... could come from us because we were breathing every so often.

Therefore, although it was important that only airborne bacteria were collected, there were few rational ideas as to how to prove that this was indeed the case.

In summary, sterilization was seen as important so as to exclude any but airborne bacteria. A few pupils believed that bacteria could be on the glass and agar before sterilization, but it appeared that even if they were on the glass after sterilization this was not as important as if they were on the agar. It seems that pupils may believe that those on the glass may not be able to grow. Most students recognized only one source of contamination and that was from the air. Understanding that sterile equipment and sterile medium are equally important to the success of the experiment is necessary to completely understand the significance of the control plate.
Pupil significance of the control plate

To ascertain how pupils viewed the control plate (plate 4) they were asked the following question: "Is there any purpose for plate 4? If so what is it?" If pupils appreciated the significance of the control plate they would be able to reason that 1) the unopened sterilized plate with sterilized agar would not produce any bacterial growth, even after five days and that 2) this would prove that no bacteria could have come from the agar or inside the glass in the other plates (1,2 and 3) if these plates were treated equally at sterilization. 3) The only source of contamination would be the air that had been let into plates 1,2 and 3 after sterilization.

Samples of answers to the above question follow:

Steven: ...so that we could see if bacteria seeped in through the glass, through the gaps or even through the glass onto the agar.

Andrew: To see if the germs could get in there. Through these little gaps at at the bottom and could see if they could go in a place that hadn't been touched with anything they can breed there.

Jane: To see if the, um, germ or bacteria could get into plate 4 while it was closed in any way.

Jonathon: ...see if there were any bacteria in the plate before we started. ...if the plate stays closed (we) would see if anything grows at all with it closed... see if any could get in, yes. If it's closed they can't really get in.

Philip: You've got to get all of it clean.

Chris: It's so you can compare the differences, so you can see how much more one's got to the one that wasn't open.
Michelle: We wanted to see what the one outside would be like and then put it against this one and see what difference there would be. It tells us that the agar was solid and it's jelly. If it wasn't clean it would be a different colour to that and it's just all one colour and you couldn't see any germs in it. You could just see what it would be in comparison with um the other two dishes but there's not really a point for having plate 4.

There were three major ideas produced by the answers to the question concerning the control plate:

1) That it was to see if bacteria could get into a closed petri dish,
2) So that we can compare this plate to the other three to see the amount of growths on the plates, and
3) To see if there were any bacteria in the plates before the experiment started.

The first two major ideas were popular with pupils. Pupils especially liked the idea of comparing the absence of bacteria in plate 4 with bacteria present in plates 1, 2 and 3. At least with this idea confirmed to themselves that the experiment had worked! The pupils who held the third idea (two, if Philip's previous statements are included) did not say how plate 4 could show that no bacteria were in the petri dishes after sterilization and before the innoculation of air bacteria. They also were unable to state that this plate would indicate a high probability that the bacteria from plates 1, 2 and 3 were from the air.

4.23 Pupils' overall understanding of the experimental procedures

Apart from sterilization and control procedures, there were other instructions that had to be taken into account in order to understand
the experiment and its results.

All the pupils interviewed appreciated the need for washed, clean hands while handling the plates in order to prevent contamination in the agar. Pupils believed that the petri dishes were placed outside, or in a draughty place or in a draughtless place to assess the different amounts of bacteria in the air currents. It was also generally accepted that the plates in the draughty exposures would catch more bacteria since there would be more bacteria "flying" over the plate and likely to drop in.

Nicola makes a statement with this view:

"To see what the difference would be if you put one in a non draughty thing there probably wouldn't be as many germs flying around the air when in the draughty one there'd be more germs flying around."

To achieve a draughtless place a cardboard barrier approximately three centimetres high was used to encircle the plate. This provided conflicting results and different explanations by pupils. Here is an example from one transcript:

Chris: Well in the draughty room the germs are blown over it and go into it more easily and when, cause they wouldn't be able to get into the cone around it so easily.

For Jane the plate left outside had more bacteria because there were more "germs" outside than in. The draughtless plate with the shield stopped germs getting in. Steven is less sure in his explanation:

"I think that in the non draughty you would get more of the, because of the um well it isn't draughty so the bacteria just goes down but in a draughty place the bacteria goes over it but if you put it outside bacteria also goes over it and it slows down and goes on it. In a draughty place it's always draughty all the time."
It was not appreciated that "local" wind speeds may be constantly varying and that by keeping the plates open for twenty minutes an average of the conditions was achieved. All pupils claimed that the plates were open for longer than a few minutes in order to allow enough bacteria to settle on the agar.

The main problem with this experiment was trying to show that the bacterial source was solely from the air. Pupils saw the need for this but failed to match up beliefs with visual evidence provided by the control. In order to understand the control and its usefulness for eliminating sources of contamination the pupils needed to appreciate that all bacteria inside the plate were potential contaminants since they all were living and showing characteristics of living things. This was not appreciated by most students since pupils appeared to have vague beliefs about the life concepts of bacteria. In this experiment pupils have revealed beliefs concerning the life of bacteria which suggests that the bacteria can be found in the air, sometimes on the glass petri dish, and sometimes in the agar medium. However, bacteria are not always viewed as living in these environments since pupils do not always recognize that they are continually undergoing division for reproduction. If this concept is held the bacteria on the glass are not mentioned as being important. A more likely explanation for possible contamination of the control plate would have involved bacteria seeping into the closed dishes rather than the sterilization process having failed and bacteria still being in the plate as a living, reproducing unit. The lack of life concepts appear to play an important part in pupils' understanding of the experiment. This will be discussed in more detail in Chapter 5.
The third phase of the study involved a second experiment "Bacteria on Ourselves" which uses the same practical techniques and will be discussed in the next section.

4.3 Pupils' beliefs elicited from Clinical Interview Three

This third phase of the study involved interviewing ten more pupils from the same second year class. After performing the first experiment it was believed that the pupils would use this prior learning experience and gain a greater depth of understanding of the second experiment. This third interview was given after the experiment "Bacteria on Ourselves" but before the results were available. This enabled pupils to predict the results they thought they would obtain. The information gained from this part of the interview is reviewed in the first subsection presented. Other subsections deal with pupils' views of the significance of sterile equipment and medium, pupils' significance beliefs about the importance of the control plate, and finally, the overall understanding of experimental procedures.
4.31 Predicted results

All pupils were asked to predict the results of the experiment. This provided a fairly uniform answer that can be summarized as follows:

Plate A Unwashed Hands: This plate was expected to have the most bacteria on it.

Plate B Washed Hands: The plate that was innoculated with bacteria from washed hands would provide a smaller source of bacteria since washing was expected to remove bacteria from the skin.

Plate C Unopened: All pupils expected this to be free from bacterial colonies since the plate had remained unopened and later they were sealed with cellotape and put in the incubator.

Justine used her home experiences to justify this prediction:

"Because it hasn't been opened and when you if you have food at home and you just close it up it doesn't go mouldy or anything."

Although the plate was closed, Mark revealed a common idea that was also apparent in the previous experiment:

"... but some could seep because if they were floating in the air and it wasn't cellotaped up and it wasn't sealed in so I don't (know). Some bacteria might have been able to come in from the air but it would spoil the experiment."

In fact, six of the nine pupils believed that the bacteria may enter the plates from contaminated air because bacteria may enter the plates if they were opened too long. Lewis provides an example of this belief:

"... because when we opened it the air got to it as well."

A third of the students believed that although there may be airborne bacteria in the cultures they could be distinguished from those on the hands. An example of such a statement is provided by Nicola:
"Well in the previous ones which we had done were all different colours but ones that just come from our hands are white ones so we could tell the difference between them cause the other ones were like they were fungi and that you know and wouldn't be able to get those on your hands and so you would have that on the agar which was from the hands' experiments."

Robert also suggests: "We could compare them with these (point to drawings of bacteria from previous experiment)." Another distinguishing factor is provided by Mark:

"There's two different kinds of bacteria probably the one in the air you know, you know is detailed. Got lots of, you know, dirty marks and that, but on your hands it probably hasn't got very much, you (know), because you wash them ...."

The predicted results show that all the pupils have an understanding of the experiment as far as an expectation of results. However, there is still some doubt about the role of plate C - the control plate in this experiment. Although the pupils believed that it would remain clear, two pupils still believed that some bacteria might be able to seep into the agar plates. Pupils appear to have learnt from the previous experiment that airborne bacteria could contaminate the plates when the petri dishes were opened and that identification of these bacteria might be useful in order to discriminate between the bacteria from the air and bacteria from the pupils' hands. Contamination of plates and its consequences as pupils see them is discussed in the next section.

4.32 Pupils' views on the significance of the sterile equipment and medium

All the pupils appreciated the need to sterilize the equipment and most pupils provided an argument as to how they knew that the sterilization had worked. Pupils had to control contamination from not
only the air, as they found out in the first experiment, but also from the equipment. Several pupils provided examples of their beliefs as to why sterilization was done.

Richard: So there aren't any germs in there so you can tell or know that you only got the germs from your hands.

Sharon: They'd been sterilized so no dirt could be on them... you'd be able to see the colours of them.

Mark: If they weren't clean the bacteria from the air and your hands would get in there before the actual experiment because we are trying to find out that bacteria are on our hands and not in the air.

Most pupils view the need to controlling contamination as important and in this interview seven pupils provided suggestions as to how the success of the sterilization procedure may be proved.

Evidence for successful sterilization are provided in the following excerpts:

Lewis: Heat them up very hot and leave them to cool down. If you put it in an incubator and take it out after a while there shouldn't be any bacteria on it.

Lewis does not reason why bacteria are absent on the plates but Robert does:

"I suppose you could test it if you put some agar in and you had a lot of them and you just took one and put some agar in it then if any bacteria grows then you know that the dish isn't sterile but if there is nothing there then you know it is."

However, there are problems still occurring with the time lapse incurred by having to wait for the bacteria to grow. There are still views that one could tell if the agar and glass plates were sterile by examining the plates immediately after the sterilization process as can be seen by the following excerpt:
Nichola: I suppose there'd be a different bacteria for that jelly because um it's meant to be sterile before we started so it would probably just have little black bits in it if it wasn't really clean.

If the sterilization process is fully appreciated pupils should be able to cite plate C as proof that sterilization has been successful and that this in turn tells us that the bacteria growing on the agar are, most probably, from our hands. The views of pupils concerning the significance of the control plate is discussed in Section 4.33.

4.33 Pupils' views on the significance of the control plate in the experiment

The two pupils who showed the most logical argument on the significance of the sterilization process connected their argument to the purpose for plate C - the control plate. This is Robert's argument for plate C: "... oh, um to test whether the dishes are sterile and um don't know about it. ... to make sure the bacteria in these plates isn't the bacteria from the actual dish or the agar." Robert indicated in an earlier interview an understanding that bacteria are able to multiply and make more germs. Deborah also revealed the belief that bacteria could reproduce themselves and claimed that plate C would prove the other plates sterile "if there wasn't any bacteria on C at the end of the experiment." Deborah did not extend this argument to eliminate unwanted contaminant bacteria and prove the bacteria growing had come from the hands only. The other pupils confidently expected Plate C to be free from bacteria but this was only because the plate hadn't been opened. Sharon suggested checking the agar with a microscope therefore indicating that she may not expect to see the bacteria easily. When asked about the purpose of plate
C, Sharon volunteered, "... to show what the plate would look like without any germs in." Sharon produced one of the more complex concept maps including the life concepts from the first clinical interview. She believed that bacteria reproduced "like families do". However, she apparently did not use this concept of reproduction when discussing the purpose of plate C.

Justine also claimed that plate C reminded us what the experiment looked like in the first place so we could see how much it changed - a common idea presented by pupils in both experiments. She saw the need for sterilizing the plates at the beginning of the experiment since she stated, "bacteria from other experiments might be on it."

Although pupils viewed the need for controlling contamination as important, the limited number of pupils being able to prove that sterilization had taken place resulted in still fewer pupils having a full understanding of the role of the control plate i.e. that 1) plate C demonstrated that sterilization had been successful, and 2) that it eliminated contamination from the agar and glass so leaving contamination only occurring from the hands. It is possible that limited life concepts may affect the way pupils view the experiment especially with reference to proving sterilization has occurred and the role of the control plate.

4.34 Pupils' overall understanding of the experimental procedures

The pupils appeared to find it easy to make the correct predictions for the experiment even though they experienced some difficulty in explaining their reasoning behind these predictions. Throughout the
interviews it was also apparent that pupils were more satisfied with obtaining an answer that they saw as correct rather than having a logical explanation. Examples of this attitude are revealed in Section 4.4. Pupils were accomplished answer seekers without being reasoners.

Pupils found the second experiment easy to perform. This was probably because it only involved three plates and uncomplicated procedures. Pupils did not attach a lot of importance to the agar in its role as a food source or as a potential source of contamination. Three pupils mentioned that the agar provided food for the bacteria while two pupils said that the bacteria did not feed on the agar. This is an indication that life concepts are not very strong and may influence the pupils' judgement as to what is going on in the petri dishes.

The air was seen as the chief source of contamination and the idea that bacteria may get up through the glass occurred on two occasions. However, most pupils appeared to have reasoned that contamination through the gap in the petri dish happen and confirmed this by predicting plate C to be free from bacteria. Beyond the physical appearance of plate C, most pupils were unable to state its role in the experiment. Sterilization had an important part to play in the task but most pupils were unable to relate this belief to any sort of meaning for the control plate.

With these conclusions in mind, it is pertinent to look at the pupils' perceptions of the two experimental tasks when parts of the experiment have limited relevance to the task, e.g. in experiment one plate 4 and in the second experiment plate C.
4.4 Pupils' perceptions of the two experimental tasks

The dialogue of two groups of pupils were recorded while they set up each experiment. The pupils were then asked to provide written answers to questions concerning the method of the experiment (provided in Appendix E). Transcripts of recordings were then produced and analyzed for pupils' views on
a) instructions being followed,
b) actions being carried out, and
c) results.
These are three aspects of laboratory work similar to those discussed by Tasker (1980).

4.41 Experiment one: "Bacteria in the Air"

The first experiment "Bacteria in the Air" produced two transcripts from a boys' group and a girls' group. These were labelled Group 1A and Group 1B respectively.

Group 1A

The boys were quite comfortable being recorded and commenced recording when they were all seated and ready to start.

The instructions on the printed work sheet were followed in a recipe-type fashion with individual pupils reading out the instructions. It appeared that pupils had glanced over the instructions before starting, but this provided confusion since they did not obtain enough information about the general plan of the experiment. Features such as how long the agar plates were open were not questioned, but strict timing of how long
the plates were open was observed. This is demonstrated in the following excerpt:

Robert: (reads) Choose a draughty place in the laboratory, take off the lid and expose the ....
Mark: Open the window - draughty place.
Steven: Yes, there is.
Robert: It says put the first one
Mark: Plate One
Robert: (reads) Expose it to the air. Yes, plate one.
Mark: (reads) For twenty minutes. Right on your marks get set.
Robert: I'll time it.
Steven: Look, there's a clock up there.
Mark: Alright, what do we do now?
Robert: Haven't you got something to put 'round it?
Steven: You put both plates out don't you?
Robert: No, only one.

Why they are following the instructions and how these fulfill the purpose of the experiment is only revealed when one member of the group asks what they are doing and why. Only one person discloses that he understands the whole structure of the experiment at this point.

(The group is labelling up the plates)

Mark: There, do it on number two, do it on the lid of number two.
Martin: What was in that one?
Mark: Er.
Martin: What was in that one? Was that the lid?
Mark: The jelly, it's the jelly.
Martin: What are we doing?
Robert: What we are doing is testing for bacteria and we've got some jelly here.
Mark: And on the windowsill in the draught.
Robert: We're testing the bacteria in the air. And here we're going to exclude (the) draught from the jelly and see...
Mark: For twenty minutes.
Steven: No, it doesn't.
Mark: It is.
Martin: How are you going to test what bacteria's in that one?
Steven: It's going to take two days.
Mark: Well this will test if there's bacteria in the air, won't it?
Robert: Yes.
Mark: And this will test to see if there's bacteria just floating about and not in the draught. What is number three then?

Mark states that the plates have to be left open for twenty minutes with the draught excluder, but he is unsure that it will take at least two
days, according to Steven, to obtain a result to the experiment. This confusion is revealed once again when the boys answered the questions about the methods used.

The boys go on to answer the questions about the experiment and they reveal a common misconception concerning bacteria seeping into the petri dish. They also show a commitment to their task in the following excerpt:

Martin: Bacteria could seep into the closed container.
Steven: Yes.
Robert: If you could break into the seal.
Mark: (Steven) Lang's just messing around.
Robert: I know and blabbing into this recorder is important....

Although the group was asked why the petri dishes had to be sterile at the beginning of the experiment, Robert inadvertently changes the emphasis of the question by only considering why the agar solution has to be clean without a challenge (from the other members of the group). All the boys agreed that bacteria would be everywhere and on our hands so equipment and hands had to be clean. Robert also influenced the group's decision that plate 4 was left open to see if anything could get in although Mark did suggest that it was left to see if it changed after being left for a while. Pupils were asked to predict their results. Although Steven has already stated that the results would take two days to assess from the plate, the other members of the group ignored this part of the experiment and produced results. Part of the problem is that Steven suggests that the dirt and dust on the plates is bacteria, but he is not totally sure about this. The others are not convinced either and probably think that if it is only dust they would not be able to write down any
results immediately so they take it to be bacteria. This may suggest that the boys perceive the recording of a result for the experiment as extremely important.

Robert: Let's have a look at (plate) number 3.
Mark: This is the worst one exposed to the most air.
Robert: The one exposed to the most air
Steven: Is that bacteria?
Robert: The one exposed to the most air

Steven: Hey look, is that bacteria?
Martin: Or the draughtiest place.
Robert: Of course it's bacteria.

Later on in the transcript:

Steven: It says you have to wait two days in an incubator.
Mark: Just say what the results are now.
Robert: Here are our results now after exposing our plates to certain whizzes and air.
Steven: On plate one we have a swirl effect with minute pieces of dust.
Robert: What was plate one, where was it?
Steven: And plate one was outside our room near a draughty door.

Mark: Plate 3 seems to have a lot of bacteria on it because it was outside on a ledge and has grains of dirt from the wind blowing bacteria onto it.
Martin: Right, is that it?
Robert: Yes.

Group 1B

This group consisted of three girls. They read part way through the instructions and then proceeded, in not quite as recipe-following a fashion as the boys and apparently with more independence from the instructions.

Nicole: We have to put this around it, don't we?
Sally: Er, yes, do that a minute.
Nicole: Do we (do) that - it says, oh that's three isn't to do a draughty thing.
Nadine: No, you can choose any number you want.
When it came to timing how long the plates were open, they were careful to be accurate. However, they could not decide how open to leave the plates and so a discussion arose:

Sally: Here, just leave it here or on the windowsill.
Nadine: Just put it near the window here.
Nicole: Inside.
Sally: Yes.
Nadine: Ajar.
Sally: Ajar.
Nicole: Just a little bit ajar.
Sally: Half way.
Nicole: Half way.
Sally: The outside one should have been ajar.
Nadine: No, it shouldn't.
Nicole: Half way.
Nadine: Um, if you want, alright.

Eventually it was decided that if one plate was to be opened half way then all the others should be placed open half way. This concept of fairness of equal conditions for each plate is not the same as the concept of fairness portrayed in the following paragraph.

The notion of fairness in this section refers to avoiding cheating to obtain the correct results. The results are seen as important, after all the experiment would be a success if bacteria grew. Although growth of bacteria is the required aim of the experiment, the bacteria must only come from the air.

Nadine: We started the experiment with clean hands.
Nicola: So that we never had any bacteria on our hands. Do you agree with that?
Sally: Yes, so we started the experiment - well, if you hadn't it wouldn't have been fair, would it?
Nicola: It wouldn't really have worked.
Sally: It would have been cheating in a way.
Nadine: We started the experiment with clean hands.
Nicola: ... to prevent getting bacteria on the plates.

However, the questions that were answered by the group were seen as something to be assessed and not as a tool that will aid their
understanding by encouraging pupils to listen to other viewpoints.

Nadine: Question 4, 'the plates were left open for a long time. Why was this?'
Nicola: Because they could get enough, to make sure they get enough bacteria.
Sally: That's quite a good answer, I think that'll do.

The answers to the questions were viewed as likely to be assessed and so some sort of answer was required.

Nadine: Is there a purpose for plate 4?
Sally: I think so.
Nadine: Yes.
Sally: What do you think, I think there probably is a reason for it, a purpose.
Nicola: Yes.
Sally: We reckon there is a purpose for it.
Nadine: We can't put reckon.
Nicola: Yes, we think there is.
Sally: It says what is it if there is one.
Nadine: Um, er, just leave it.

(Discussion goes on)

Sally: Have we got to do question 5?
Nadine: Oh, shut up.
Nicola: Listen, to leave on that hasn't got bacteria on it and to leave open one that is you could see the difference maybe.
Nadine: That's probably the idea, yes yes, just write that down anyway.
Nicola: Go on then.

This gives the impression that the idea will do although it is not certain that the statement answers the question correctly. Any internal conflict within Nadine is quelled by having an answer for the question.

The two groups of pupils worked through the experiments with different styles. Both were negligent in reading through all the instructions to the experiment prior to commencing the setting up of the experiment. However, the girls appeared to reflect more on the construction of the experiment and perceived no problem in reordering the order of completing each activity with the plates. The boys were far more
concerned with following the experiment in a recipe-like fashion.

The boys' reflection on their activity only occurred when one member of the group asked what was happening and how the bacteria were going to be tested. This resulted in the pupil organizing his own thoughts about the experiment. In the other group, the girls decided that being fair in opening the plates all the same distance was important therefore showing that they considered the process in the experiment.

Pupils only began questioning procedures in the experiment when they became involved in answering the questions provided by the researcher. In the boys' group there was an incident that suggests that pupils view the questions as a task not an opportunity to clarify their ideas concerning the experiment. The task is to answer the questions as quickly as possible even if it requires a restructuring of the question.

4.42 Experiment two: "Bacteria on Ourselves"

Again there were two groups, one female, one male who recorded their progress through the experiment. Unfortunately, the girls edited their tape during the experiment by switching it off between procedures, therefore cutting out the excerpts of discussion that show the progress in argument resulting in understanding the experiment. This is an interesting move that the girls made. Obviously they did not appreciate that their discussion was of any value to the teacher. Perhaps this is a reflection of how they view their work and how they see all school work being assessed in its final form and not during its synthesis. Further discussion on these attitudes and others reflected from these group work transcripts is provided in Chapter 5.
Group 2B

This group, comprised of three boys, quickly engaged themselves with the experimental tasks without any problems. Previous experience should have helped and they also only had to use and open two plates while the third was left alone and unopened.

From the transcript it was not apparent whether they read all the experimental procedures prior to inoculating the plates. These pupils did not show any signs that they were mechanically following the procedures listed on the work sheet since it appears they quickly decided on the practical procedures of the experiment.

After setting up the plates this group embarked on answering the questions. The questions were not seen as important. Between diversions to look at the laboratory animals it took little effort to agree on the answers to the questions. Only when they came to discuss plate C was there uncertainty and Chris attempted to air his views.

Andy: Do you think bacteria will grow on plate C?
Michael: No.
Andy: No, because....
Chris: No, because it hasn't been opened.
Andy: Because it hasn't been, well it might have been.
Chris: Yes, because the bacteria....
Michael: Plate C.
Chris: I know, because the bacteria could be out (side), could get through to the plate.
Andy: No, I don't think so.
Chris: No, that's good.
Andy: Just put no.
Chris: Well I think it should.
Andy: Well you're wrong.
Michael: Two against one.
Chris: What's number five? No, what's number six?

Although Andy does not give reasonable objections against Chris's
argument, he succeeds in gaining Michael's approval and Chris gives up his challenge. The transcript shows that group pressure wins this discussion and this results in Chris not participating in the rest of the discussion.

Andy: Why do you think we had plate C? Er, to....
Chris: Because we could.
Andy: To see if bacteria could grow in plates taped up?
Michael: Yes.
Chris: Come on question number seven, we are on the last one.

It appears that the dynamics of the group have prevented Chris from developing the conversation any further. This may be a tactic of the other members of the group if they consider answering the teacher's questions as the task and do not view other pupils' views as helpful in clarifying their own views of the experiment.

Although the practical work does not appear to have been very stimulating, this is perhaps a reflection of the dynamics of the group. Individual interviews provide much more insight into an individual pupil's thinking about specific concepts and laboratory procedures, but these transcripts have the merit of disclosing some very relevant problems of teaching laboratory work and the use of group work in laboratory situations. These issues will be discussed in more detail in Chapter 5.

4.5 Results of group work (written answers)

For both of the experiments, the pupils worked in groups of two's or three's and after each experiment they were asked to reflect on aspects of the experiment and record their ideas on an overhead acetate sheet with the intention of later presenting their answers to the class. From the analysis of these data sources it is possible to look at the substantive
beliefs of a large proportion of the class concerning the sources of contamination, sterilization procedure, and the role of the control plate in both experiments. For the first experiment there were eleven examples of group work and from the second experiment there were nine pieces of group work presented.

"Bacteria in the Air"

Pupils claimed that the sterilization procedure, implemented before the practical work commenced, resulted in all the plates being free from bacteria. A popular belief about sterilization was that once it was done it was successful. Five groups reasoned that sterilization was necessary to prevent bacteria being present in the dishes before the experiment began. None of the pupils explicitly claimed that the potential contaminating bacteria from the agar or the glass plates could be mixed with airborne bacteria in the first experiment, but there were justifications suggesting that bacteria would be present if sterilization didn't take place and that these would nullify the experiment.

All the pupils appreciated that our hands could introduce contamination into the plate, either in the form of "dirt", "germs", or bacteria. Two groups mentioned that the "germs" could spread onto the jelly. This suggests that the pupils either view the bacteria as having the potential to move or to grow and cover the agar.

Predicted results for experiment one showed that pupils expected the jelly to show "blobs" of bacteria or germs that mark the agar. Three groups believed that the amount of bacteria covering each plate would depend either on the amount of air that the plates had been exposed to or
the situation in which the plates were placed. One group suggested that the plate that had been covered the whole time (the control plate) would have no germs.

When asked the purpose of plate 4 (control plate, experiment one) another group suggested that this plate would be germ free but would also act as a comparison for the other plates. Three groups believed this, while two groups suggested that perhaps it could test if bacteria could seep into the plate. Another group suggested that plate 4 had a purpose to show that no bacteria could contaminate the agar. Although they did not clearly verbalize the role of the control plate, their previous thoughts concerning the purpose of the sterilization process suggests that they have a clearer concept of plate 4 than most other groups. They stated that after sterilization "no germs could create on the dishes and they (the dishes) would be sterile." Their statement "... their is a purpose to plate 4. No bacteria can get to it" may be a reflection on the previous statements cited by this group, but none of the groups went on to say what plate 4 would be able to prove.

In the second experiment seven groups thought that bacteria would not grow on the control plate; four of these suggested that this was because the plate hadn't been opened. All have assumed that sterilization was successful. Two other groups probably held this assumption, but these pupils believed that there may be a chance of the bacteria entering through the "gap in the jar" or just by getting through to it. Another group did not think this "seepage" was possible because the bacteria could not get into the dish. This group later went on to say that plate C (the
control plate) was in the experiment "because we can see if bacteria can grow on an unopened plate." They did not reveal where they thought the contaminating bacteria would have come from so they could not be said to have grasped the total meaning of the control.

Although, in the second experiment, the pupils put forward the view that no bacteria would grow on the control plate, this plate still held little importance for them. The control did take on some meaning in each group but mostly in a comparative role. Four groups believed in this role ignoring the obvious that it was easy to compare something in plates A and B against "nothing" in plate C. The use of this idea increased in this experiment while the notion of the control being useless decreased to nil. This could be a reflection of the influence the first experiment had on the pupils' perceived functions of procedures in the experiment. Also on the increase was the belief that the control plate was to check if bacteria were seeping into the experiment. Three groups believed in this despite, in the previous experiment, having evidence that this was unlikely to occur since past control plates had negative bacterial growth. Two groups wanted to see that no bacteria had grown in the control plate, but they did not explain what this would prove and they did not suggest where the bacteria may have come from.

This written work shows that in general the pupils have not appreciated the full extent of the sterilization procedure and how this is linked with the role of plate C. Although they hold a general idea that bacteria are everywhere, pupils do not explicitly state where contaminating bacteria could have come from and how this could be proved.
However, it must be said that pupils attempted to reason the purpose of the sterilization procedure instead of dismissing it as a task that is just done and the control plate gradually took on a purpose – for some this was still the comparison of plates, for others to see if bacteria could seep in, and for a small number to see that bacteria will not grow. This latter concept goes part way towards a more scientific explanation of the purpose of the control plate, but development of this concept may depend on other beliefs such as nature of life processes that bacteria possess. The influence of these other beliefs and their possible interplay with pupils' perceptions of the experiment will be discussed in the next chapter.
CHAPTER FIVE

5.0 Introduction

This chapter discusses pupils' beliefs about bacteria and examines the way in which pupils' beliefs concerning bacteria interact with their understanding of experimental procedures involved in the two experiments used in this investigation. The chapter reviews pupils' use of prior beliefs when identifying bacteria on the agar plates, looking at colonies and their varying sizes, explaining the purpose of sterilizing the medium and petri dishes, and the role of the control plate.

From the analysis of the data it was found that some concepts are useful in helping pupils explain significant aspects of the experiments. The concepts of growth and reproduction were useful in explaining the importance of the sterilization process and the role of the control plate. Other pupils who did not possess the correct scientific framework of these concepts were less successful in interpreting the data obtained from the two experiments. Section 5.3 is a discussion of the use that some pupils make of their concepts when explaining the purpose of the sterilization process and the role of the control plate.

The analysis of group work transcripts and the written work produced by these groups revealed pupil attitudes towards laboratory work. The importance of these attitudes and pupils' prior beliefs is discussed, with reference to teaching strategies, in section 5.7. Suggestions for further research are presented in the final section of the chapter.
5.1 Discussion of pupils' beliefs about bacteria

The initial interview of thirty-one pupils produced pupils' substantive beliefs concerning bacteria. It was not surprising to discover that pupils have beliefs about bacteria prior to formal instruction since the life experiences of a child in today's world would provide many learning opportunities, e.g. visits to the dentist or doctor, and watching television.

The concept of a bacterium is not isolated from other concepts. The multiplicity of the pupil's concept of bacteria can be seen as a set of relationships between concepts within a conceptual framework. To clarify the relationship between concepts and to graphically demonstrate the resulting framework, concept maps can be used (see Appendix A2). In each map there are many different concepts making up the composite belief of bacteria. Some concepts e.g. the concept "small" are well defined and present in many of the pupils' frameworks. Others such as the concept "bacteria are living" are present but do not possess subsuming concepts that give meaning to the concept. This may be because the concept of "living" is not well understood, particularly with respect to micro-organisms.

Many pupils believed that bacteria were living, but pupils' beliefs about bacteria varied throughout the class because each pupil held a variety of related subsuming concepts that made up his/her beliefs about bacteria. The meanings attached to the relationships between these subsuming concepts gave variety to the pupils' conceptual frameworks. For many pupils the concept "living" assumed a different meaning with respect
to their beliefs about bacteria, but the heterogeneity of the belief is a result of the relationship between concepts in the conceptual framework.

Concepts make up the framework of pupils' beliefs about bacteria. These concepts, as has already been stated, are not isolated from each other. Teachers could be more effective if they recognize these concepts and researchers discover how they are related to each other. In the results section (4.1) it was recorded that many pupils viewed bacteria as small microscopic "things" that cause disease. These diseases are thought to spread from animals or, more commonly, from people breathing, coughing and sneezing. It was thought that different diseases were caused by different types of bacteria and some pupils reasoned that in order for diseases to occur, bacteria must be alive. A few pupils declared that bacteria had to be alive to get into our bodies and to know where to go. Many pupils possessed alternative concepts of "living" which were distinguishable from the scientific concept since few scientific characteristics were used. This supports Looft's (1974) findings that many pupils have an incomplete understanding of living according to associated biological attributes such as nutrition, respiration, reproduction, etc. The concept of life has important meaning in the way pupils perceive bacteria to function in the context of the two experiments studies.

It was anticipated (1.31) that the pupils' conceptual framework of bacteria might influence the pupils' understanding of the experimental content examined in this study. If the experiments are examined in detail it can be seen that in order for the pupils to interpret them correctly,
pupils need to be able to use a number of concepts that make up the conceptual framework of bacteria. In both experiments pupils need to appreciate that bacteria are widely distributed in the environment if they are to predict the results of the investigations. Most pupils appreciated that bacteria are widely distributed since most claimed the widespread existence of bacteria in the initial clinical interview. This idea is necessary for understanding the possibility of contamination of the sterile petri dishes and media used in the experiments. Another concept required to understand how contamination might occur is that of bacteria being living units. Of the seven supporting concepts that contribute to the concept of life, that of reproduction is the most fundamental to these experiments since if reproduction does not occur, the bacteria do not become visible as colonies. The concept of reproduction can be used to explain the increase in the size of bacterial colonies. Pupils may not be able to differentiate between the growth in the size of a bacterial colony involving many cells and the growth taking place in one cell. For growth to take place, whether it be multicellular in terms of colony growth or the increase in the size of one cell, a source of food is necessary. The concept of nutrition to support growth and reproduction in bacteria is a prerequisite concept to understanding the living nature of bacteria. Thus it seems evident that pupils are required to have an understanding of a number of related concepts in this area before it would be reasonable to expect pupils to understand the two experiments in this study.

If the pupil uses the term germ or bacteria it places the pupil's mastery of the concept at level one on Klausmeier's (1976) five levels of mastery. The ability to give meaning to the concept by showing knowledge
of all the defining attributes of the concept promotes concept mastery to level five (Klausmeier, 1976). Although all the attributes of bacteria are not required, bacterial life concepts are important in understanding the experiments in question. In order to reach mastery level five for the concept of bacterial life the pupil would need to classify instances of nutrition, excretion, sensitivity, reproduction, growth and movement. To understand these experiments pupils should have concepts of movement, reproduction, growth and nutrition in relation to bacteria. From the results obtained it is found that pupils commencing these experiments do not relate concepts of movement, reproduction, growth and nutrition to bacterial life. These appropriate concepts were held by only two pupils in the class and these were held in relation to the general term "living things" and not specifically to bacteria. Other pupils did not possess any understanding of bacteria as living organisms. In the initial interview pupils were not asked about the continuity of life in bacterial colonies, but Tamir et al. (1981) reported that 45 % of his grade 5-9 sample of pupils understood the continuity of life and 36 % realized that living organisms originate from other living organisms. This would be an important concept to hold if one were to ask the pupils to predict the results of the first experiment. This task would be unrealistic for the pupils since only one pupil had previously seen bacterial colonies. The identification of bacteria was not problematical for pupils since they showed that they had basic ideas of sorting things according to physical properties such as shape, size, etc. The acquisition of sorting skills associated with classification was most probably obtained in the previous school year and reinforced with everyday experiences. It was also expected that pupils would have a greater mastery of the concept of living
since this concept was taught in the first year science syllabus.

Pupils approached the two experiments without, in the researcher's view, sufficient scientific conceptual knowledge to be able to make meaningful conclusions from the resulting data. The occurrence of this type of situation is never intended by teachers. However, in the researcher's experience, this cannot be unusual since it was the researcher's expectation that pupils would have reached higher levels of mastery in the concept of life as a result of prior learning experiences and only through the initial interviews were the concepts of bacterial life found absent. The researcher's findings confirm Tasker's (1981) conclusions that pupils' knowledge structures, against which learning experiences occur, are frequently not the structures the teacher assumed pupils had. This would seem to compound patterns of teaching new concepts since the "building blocks" of the concept may not be there or, if present, possess different relationships than those possessed by the teacher. In this study remedial work was not embarked on and pupils commenced to use their knowledge in the two experiments. The results of the pupils' endeavours to understand the two experiments are discussed in the following sections.

5.2 Discussion of pupils' interpretation of the experiments in the study

This section describes the role played by pupils' beliefs as they relate to the pupils' attempts to interpret the experiments "Bacteria in the Air" and "Bacteria on Ourselves". These beliefs were revealed during the second and third clinical interviews respectively, which took place
after the pupils had performed the experiments. An account of these beliefs was presented in Chapter Four of this study. In their interpretations of the first experiment the pupils illustrated that they were able to identify bacteria. The concept of many bacterial cells making up a colony seems to be held by many pupils. However, pupils found it difficult to explain why the colonies varied in size.

Pupils were unsure of the purpose of the sterilization procedure and the significance that possible unintended contamination through failure of the sterilization process may play in obscuring the results. As a result of the absence of these "ideas" it was not surprising that pupils did not understand the significance of the control plate since this requires some understanding of the sterilization process.

In the second experiment it was expected that the pupils would use ideas generated from the first experiment and have a greater depth of understanding of the purposes of the sterilization procedure and the role of the control plate. In summary, pupils provided uniform predicted results for the second experiment. The pupils hypothesized that the "dirty hands" plate would have the most bacteria and all the pupils predicted that the control plate would be free from bacterial colonies. Pupils believed that contamination of the plates was most likely to come from the air resulting in a mixture of the airborne bacteria with bacteria obtained from pupils' hands. To prevent this, the plates were not opened for more than a minute. However, if airborne bacteria were let into the petri dish pupils thought that it would be possible to identify these from those from a pupil's hand by the colour of the bacteria. All the pupils
thought the sterilization process was effective and more pupils were aware that knowing the sterilization process was successful was important. These latter pupils offered methods of substantiating the sterility of the equipment. However, many pupils still expected that proof of sterilization could be obtained immediately after the sterilization procedure. All pupils stated that the control plate would be free from bacteria, but some pupils still believed that bacteria would be able to seep into the petri dishes through the "gap" between the lid and the base. Only two pupils claimed that the purpose of the control plate was to test the initial sterility of the plates and that this plate could also show that bacteria were not seeping into the petri dishes.

5.21 Analysis of the concepts required to understand the experiments

In both experiments pupils were required to identify bacterial colonies on the agar in order to obtain experimental data. Before experiment one "Bacteria in the Air" most pupils had not had any previous experience in identifying bacteria and so could not rely on their prior beliefs to assist them in identification. However, prior beliefs about bacteria could be used in the justification of the growth of colonies and the spread of bacteria on the plates.

Concepts may influence the pupil's view of the scientific procedures used in both experiments. The important scientific procedures are the sterilization process and the role of the control plate. Concepts of bacterial life are required in order to understand these two features. To understand the necessity for sterile media and equipment the word sterile must have meaning for the pupil. The scientist would immediately
conclude that the medium did not contain any living micro-organisms. Living organisms would be regarded as those that fulfill the seven characteristics of life. Pupils should also appreciate that any form of life on the agar would be regarded as contamination and result in unsterile conditions. Therefore, understanding the contamination of the agar and the petri dishes requires the pupil to have concepts about bacterial life. If there is contamination from the agar the scientist would recognize that the agar provides nutrients to support life. Evidence that the bacteria on the plates are living is provided by the growth of colonies on the agar. The idea of growth of a colony by cell division is an essential subsumer concept in the concept of bacterial life.

There is also the possible contamination of sterile agar from unsterile petri dishes. Scientists understand that bacteria may spread onto the agar which provides support for life. The sterility of the medium, agar and the petri dish is important and it is necessary to confirm this in order to be able to state from which sources the bacteria on the plate were obtained from. If sterilization preparations are performed satisfactorily the unopened control plate can prove the required sterility of the equipment and media.

The underlying roles played by a variety of concepts related to the life of bacteria has been discussed, it is now necessary to look at how the pupils' concepts of bacterial life influence their interpretation of the experiments.
5.22 Pupils' prior beliefs

5.221 Identification of bacteria

Pupils had to identify bacteria on the agar in order to obtain experimental data. Identification of bacteria requires the pupil to correctly assign the organism to a distinct group. Pupils were able to identify different types of bacteria from the agar by the colour of the colonies. In the initial interview pupils did not use the criterion of colour for identification of different bacteria. Eight out of thirty-one pupils in the initial clinical interview used shape to differentiate between the different bacteria before; they had actually seen any examples of bacteria. When it becomes apparent that the microscopic world of bacteria is smaller than pupils previously imagined shape as a criterion between different bacteria loses its appeal. Students were able to see the limitations of the concept of shape to sort bacteria in this situation and substituted the criterion of shape for another criterion that would allow visual data to be more manageable. They used colour to separate bacteria that may be on pupils' hands from bacteria obtained from the air. This was suggested by pupils interviewed after the second experiment who were asked how it was possible to differentiate between bacteria obtained from sources such as the air, the agar, or from the hands. Their answer was probably enhanced by the variety of coloured colonies visible on the plates used in the previous experiment. Coloured colonies may have detered pupils from using the control plate to detect contamination from unsterile agar.
5.222 The concept of bacterial colony

Analysis of transcripts showed that pupils were able to explain the concept of a bacterial colony in terms of the colony being made up of many bacteria. Although pupils were able to describe a bacterial colony, they were unable to explain why the colonies varied in size. Pupils used their concepts of growth and reproduction, but they did not have sufficient mastery of these concepts to allow themselves any profitable insight to explain why colonies varied in size. For example, Jonathon was unable to explain why some of the colonies were larger than others. His initial interview reveals that he perceives bacteria as living. He supported his statement with beliefs that bacteria feed on blood and that chemicals kill them. However, these are not concepts that can support an argument for different colony sizes. Another pupil, Steven, who had only one reason for bacteria being alive was able to give a logical reason to explain the different sizes of the colonies. Steven's concept consisted of bacteria reproducing themselves every twenty minutes. This was a useful conceptual springboard that enabled the question about varying colony sizes to be answered. Philip also used his concepts revealed in the first clinical interview to answer this question. A visit to the dentist had resulted in a discussion about tooth decay. Philip revealed that bacteria "grow and sit and multiply in the teeth". He used his life concept of bacteria multiplying to explain that bacteria could spread all over the agar. Concepts of bacterial life can achieve greater stability and be incorporated into broader conceptual frameworks if they are able to provide acceptable explanations to questions.

The explanations about bacterial colony size appear to be related to
how the pupils view the life functions of the bacteria. Bacterial life concepts are important since the size of the colonies is related to the reproductive function of the bacteria. In the present study it would seem that many pupils do not have sufficient knowledge of these life concepts to be able to relate their beliefs to the observations made in the experiment. It is postulated that the concept of bacterial life is necessary in order to understand the spread of bacterial colonies on the agar.

5.223 Pupils' concept of sterilization

The application of bacterial life concepts and in particular those of growth and reproduction to support the significance of sterilization of the agar and the petri dishes is essential. From the analysis of answers to questions in the three clinical interviews there appears to be three categories of pupils. The largest group of pupils consists of those pupils who do not hold life concepts related to bacteria and cannot support their reasons for claiming the success of the sterilization process. The second group possessed life concepts but did not use them; the smallest group held the bacterial life concepts of reproduction and used them to produce a valid argument for the proof of the sterilization procedure being successful.

In the first experiment pupils who could not give adequate reasons to substantiate the success of the sterilization procedure were found to have no concepts of bacterial life. Their reasoning included the assumption that because the sterilization procedure had been performed, then it was naturally a success. However, all these pupils did appreciate the reasons
Perhaps more interesting are the speculative reasons as to why pupils of the second group did not use their prior concepts of bacterial life. Nicole was one of these pupils. Nicole's prior beliefs about the life functions of bacteria included a statement that bacteria were living because they could be seen growing. The concept of growth in colonies of bacteria is required in order to reason about sterilization. To substantiate that the plates were sterile the pupil would have to understand the meaning of the word sterile. This would also entail recognizing that since the control plate was not opened there would not be any growth of bacteria if the agar and petri dish were sterile. It would be expected that Nicole's concept of growth would have helped her with the proof of sterilization. She wanted to check for contamination of the plates by examining the agar with a microscope to see if there were any bacteria. She may have been under the impression that growing bacteria can only be observed by using a microscope. The worksheet provided for the experiment stated that colonies of bacteria would easily be visible to the naked eye after a few days. Analysis of the group work transcript showed that Nicole and her work colleagues had not read all the instructions to the experiment before commencing, thereby missing an important piece of information. Nicole appreciated that contamination could come from the air and also from unwashed hands but did not record that bacteria may come from the equipment. Nicole speculated that since the control plate was unopened, contamination may be occurring through the "gap" between the lid of the petri dishes and their bases and that the control plate would test for this. In another example, Steven's life
concepts supported him in his concept of sterilization, killing the bacteria in the petri dishes and ridding the plates of unwanted bacteria. However, he did not use his concept that included ideas of bacterial cells dividing to prove that the plates were sterile because the control plate was free from bacteria. Like Nicole he also though the the control plate would indicate if bacteria were seeping through the gap or even the glass.

Pupils learnt from the first experiment that bacteria are widespread in the air and that these bacteria could be grown on the agar. Most pupils appreciated that there could be contamination of the plates by bacteria from unwanted sources. However, few suggested that the agar and the petri dish could still be contaminated after sterilization if the process had not been completed properly. Only two pupils viewed the agar as a source of food but neither of these pupils claimed that the agar should be sterilized along with the glass petri dish. It appears that pupils did not connect the agar with any concept of life and therefore no real need for sterilization was seen. It is more understandable that pupils do not regard the petri dish as a source of contamination since it is not an obvious food source.

In the second experiment three pupils provided a scientific reason for the success of the sterilization process. They did so by using their concepts of bacterial life which other pupils did not possess. Two of these pupils argued that the control plate was used to prove the sterility of the plates before the experiment started. Nichola argued that bacteria would not grow on the plates if the plates were sterile but did not relate this proof of sterility to the function of the control plate. Many of the
pupils showed in their written work that they could not establish if the agar and the petri dishes were sterile at the beginning of the experiment and possessed alternative perceptions of the control plate than those that would normally be held by the scientist.

5.224 Pupils' perceptions of the role of the control plate

Most pupils viewed the role of the control plate as a comparison against other plates. Some pupils used it to check if any bacteria had entered the plate through the "gap" between the lid and the base. The construction of the plates may have contributed to the ideas held by many pupils. In everyday life the seal of a jar is expected to be tight if things are to be kept in or out. The glassware of the petri dish is loose fitting and may give the impression that a seal was absent. However, all the pupils had the opportunity to prove that bacteria were not entering the plates by this method because at the end of the experiment the control plate was free from bacteria. Only Michelle used this evidence to argue against the notion of bacteria seeping in.

Seven of the nine pupils interviewed in the second experiment could not provide a proof of sterilization and the control plate was still viewed as a comparison between other plates. The pupils with adequate bacterial life concepts concerned with reproduction or growth, at a multicellular level, were able to justify their reasoning for the sterilization process and the control plate. Of the bacterial life concepts those of reproduction or growth concepts with reference to cell division were the most useful. Some pupils added to their concepts through doing the experiment, but they often did so in a less than
satisfactory way because these newly acquired concepts could not be used to generate the scientific meaning for the procedures used in the experiment.

"A child who has really learned something can use it, and does use it. It is connected with reality in his mind, therefore he can make other connexions between it and reality when the chance comes. A piece of unreal learning has no hooks on it: it can't be attached to anything, it is no use to the learner" (Holt, 1975, p. 104).

Experiments may change the relationship between concepts or add new concepts to conceptual frameworks but not necessarily in accordance with the scientifically preferred meaning. The environment beyond school provides pupils with a rich source of concepts that may be interpreted in different ways but we cannot guarantee that these new concepts are interpreted in the same way as scientists would interpret them.

5.3 Pupil held concepts affecting the understanding of the experiments

This section will examine the effect that the concepts of sterility and growth have on a pupil's understanding of the experiment. The nature of these concepts may hinder or aid the pupil's understanding of the procedures used in the experiments studies.

5.31 Pupils' concept of sterile

At the beginning of the experiment pupils received an explanation about how the sterilization process was performed. In transcripts from clinical interviews most pupils showed that they understood the meaning of sterile in the context of the experiment. However, it was found that alternate views of the meaning of sterile did alter pupils' perceptions.
of the experiment.

Nichola provides an example of an alternate perception of the experiment. She began the two experiments with no evidence of concepts related to the life of bacteria. Her homework revealed that after experiment one she could not provide evidence that the sterilization process was successful. In the second experiment Nichola suggested that the control plate acted as a comparison showing the difference between the plates that had bacteria on them and the plate that did not have any bacteria on it at all. In the second clinical interview Nichola suggested using a microscope to check if the plates were sterile. Later she suggested putting the plates in a sterile room. Nichola claimed that anything that was sterile would stop bacteria growing and that the plates were sterile if they were not dirty. She suggested that in some instances the agar might not be sterile so then the bacteria would grow on the agar. Nichola thought that the plates had bacteria on them because none were placed in a sterile room. She stated that a warm room (or incubator) would have more bacteria in it. It is inferred that the need for a sterile room suggests that she believes that the bacteria are continually getting into the plate. If they did and the agar was "sterile", according to Nichola's meaning of the word, then the bacteria would not grow because the agar would not support growth.

Nichola's concept of sterility consisted of bacteria being on the plate but not growing because the agar was sterile. This is not compatible with the scientists' view of sterility but can be used to support the role of the control plate in a limited context. Nichola would think that
plate C was sterile as she claimed in her interview, but she would not be able to use this information to confirm that the other plates were sterile. The inadequacies of her argument perhaps are obscured because the other plates are innoculated using bacteria from pupils' hands and pupils are attempting to prevent contamination from the air. Nichola not only appears to have an unstable concept of sterility because she cannot decide if sterile means to prevent growth (which could come from the human reproduction sense) or to be without life, but she also perceives the experiment in different terms by presumably thinking that bacteria can get into the plates from outside. Other pupils who view bacteria seeping into the plate may also hold Nichola's concept of sterility and therefore can still reason why the control plate was not contaminated with bacteria after each experiment.

5.32 Pupils' concept of growth

Pupils acquire concepts from many different sources, e.g. watching television, listening to other people's ideas, doing experiments. Sometimes these concepts are stored in long term memory and used again only when appropriate links can be made to new incoming information (Freyberg and Osborne, 1981). If these prior concepts can be used and they provide new insight into a novel situation, then they could act as building blocks to further concept development. In some other instances concepts may be inappropriately linked to aspects of new information and therefore become stumbling blocks to further concept development.

From analysis of the data provided by clinical interview three, three pupils had concepts of bacterial growth but did not use them. One of
these pupils learned about bacterial growth from watching a television program. Her growth concept was based on watching bacteria being plated on agar and put in the refrigerator to grow. Since the circumstance of the class experiments were different (an incubator was used), Sharon was unable to make an appropriate link with her growth concepts of bacteria present in long term memory. Sharon's concept map possessed the most bacterial life concepts compared to other pupils but some of these concepts were the result of misinterpreted information. These concepts now hindered comprehension of the experiment. Two other pupils who used concepts of bacterial growth developed their concepts during the course of the experiments because they were not evident in the initial interview. It seems that pupils who have come to the experimental setting with few previous ideas about bacteria cannot achieve an understanding of the results and purpose of the experiment.

At an elementary level there are two related beliefs that can be held concerning bacterial growth - that of an increase in individual cell size or that of cell division to increase the numbers of cells in a colony and so increase the size of the colony. If pupils state that bacteria grow and become visible on the plate this statement does not reveal which concept of growth the pupil is using. It is speculated that pupils who use the concept of the bacterial cell enlarging will not be able to make as much use of this concept as the pupil who believes that the bacterial cell can undergo cell division and produce a replica of itself. This latter concept can be used to explain the large numbers of bacteria present in the air and the potential source of bacteria from one bacterial cell present in the unsterile agar.
It is speculated that pupils who do not use their concept of growth in their explanations perceive the concept of growth, related to bacteria, as an increase in cell size. This concept can be related to everyday life, pupils observe their brothers and sisters growing without the notion of cell division - the organisms simply become bigger.

5.33 The influence of concepts on problem solving

Chapter Two speculated that difficulties with problem solving could be the result of the lack of linkages or inadequate knowledge structures that pupils possess. Pupils are often unable to connect their constructed meaning of the problem to their knowledge structures. Many of the pupils interviewed for this study had inadequate knowledge structures about the concept of "living" to be able to apply these concepts to prove the success of the sterilization procedure and explain the role of the control plate. Osborne and Wittrock (1983) observed that pupils had difficulty with starting the problem. If as Case (1974) suggests, pupils chunk their sensory information, they could begin the problem by asking themselves "why does bacteria grow on all but one of the agar plates?" Their reasoning pattern to solve this question for the first experiment, using Case's analysis, could be chunked into salient information units such as:

1) Why does bacteria grow on all but one of the plates?
2) It could be that the air let into all but one plate had bacteria.
3) It could be that the agar was not sterile at the beginning.
4) If the agar used was the same in all the plates it can't be the agar.
Pupils do not ask themselves this first question but never the less pupils do produce the second statement if they do not believe that bacteria are seeping into the plate. However, many pupils do not produce the third informational unit since most take for granted the success of sterilization and do not question the sterility of the agar. To check the sterility of the agar some pupils suggested that a microscope could be used. Pupils appreciated that bacteria were microscopic but did not appreciate that the use of the microscope would only confirm bacteria being there and not that they were living or growing. Only a concept of growth in terms of bacterial cell division would generate meaning for the pupil and help explain the exponential increase of bacterial cells in the colonies that results in the bacteria being easily visible. Pupils without concepts of cell division are hindered in obtaining proof of the sterilization process. This proof is required to make information unit three salient. Robert and Philip could reason through the four information items since they had shown in their initial interview that they had concepts of reproduction and growth that allowed them to make the information items salient. Both reached the correct conclusion as to the role of the control plate.

Steven and Nicole did not use their concepts of life to rationalize the role of the control plate and could not reach a conclusion because their concept of the sources of contamination could not support the statement made in information item two. In their view air may have been let into all of the plates because of the "gap" between the petri dish lid and the base. In this instance the perceived physical nature of the experiment may be more powerful than the concept of bacterial life in
determining the success in providing a reason for the role of the control plate.

In this section we have concluded that concepts of bacterial life play an important role in the understanding of the experiment. The level of mastery of these concepts is important since the experiments demand that the pupil identifies instances when the concept of growth and reproduction are relevant. If pupils do not view the life of bacteria using concepts of growth and reproduction then the whole point of the experiment becomes meaningless. In some cases alternative concepts are used in the interpretation of the experimental data. This is demonstrated when pupils view the bacteria infiltrating the seal of the plate.

For the teacher, prerequisite knowledge of the pupils' prior beliefs about bacteria is essential in order that any effective learning be encouraged. Pupils are able to modify their frameworks through experimental tasks but in many instances, their frameworks of concepts still remain inadequate in providing meaning for the experiments.

5.4 Discussion of group work (written answers)

Pupils produced answers to the questions displayed in Appendix E for experiments one and two. These questions were intended to provide details of the substantive beliefs held by the class about the sources of contamination, sterilization procedure, and the role of the control plate.

Analysis revealed that pupils perceived sterilization as a means of disposing of any bacteria they may have been on the plates prior to the
experiment. The sterilization of the agar appeared to pupils to have little relevance to the experiment since bacteria from the air or hands were considered as more probable contaminants. Few pupils believed that once the sterilization procedure was complete, unintentional contamination could occur from within the plates. Some groups believed that the control plate was part of the experimental design so that pupils could compare the differences between all the plates while others thought that the control plate held no purpose. Another group, who believed that bacteria could seep under the petri dish lids, thought that the control plate was designed to test if this happened. This hypothesis for the role of the control plate was more popular in the second experiment although the first experiment could have provided evidence to the pupils that bacteria could not seep into the dish. Pupils attempted to generate more meaning for the second experiment by actively thinking about the reasons for the sterilization process and proof for its success, rather than accepting that once the technique is completed it is a success. The control plate became useful in various ways rather than having no purpose in the experiment. These changes in viewpoint may have been influenced by the continued inclusion of these processes in the second experiment and the repeated questions asked about sterilization and the control plate after each experiment.

Written work provided by groups is similar to written work provided by individuals for an exercise after the experiment. From written work the teacher can obtain a sense of the beliefs held by pupils. However, as an assessable piece of work it has limited use. Take for example question number 7 on the question sheet "Bacteria on Ourselves" (Appendix E), "why
are the plates placed in a warm incubator?" Seven groups out of nine believed that bacteria grow in the warm incubator. Of those seven groups only one group mentioned that apart from growing, the bacteria will reproduce, or in the pupil's term "breed". Some of the groups justify their reasons for their answers, but from their justifications we still have a limited idea about the pupils' concepts of growth. Written answers are unlikely to reveal sufficient information about the extent of pupils' concepts. Teachers assume that pupils know the meaning and implications of the words they use in written work. On these assumptions teachers assess and categorize pupils as having learned or not learned the desired concepts.

The written questions and answers were useful in this study as indicators that beliefs revealed in the clinical interviews by some pupils also reflected the beliefs held by other class members. However, the researcher is not able to assess the pupils' mastery of the concept to the same extent as in the clinical interview. Pupils with a more comprehensive understanding of the growth of bacteria would be able to distinguish between the growth of individual bacteria and the growth of bacterial colonies. This insight into pupil generated meaning is only apparent if one investigates the pupils' substantive beliefs by using more in depth probing measures such as interviews rather than written questions.

This section reveals that similar written assessment techniques used by teachers lack the sublety that is required to assess pupil performance in laboratory written work. Other methods of assessment would be more
useful to determine the conceptual understanding of the pupils. Section 5.7 reviews the problem of assessment of laboratory work.

5.5 Perceptions of experimental tasks

The perceptions that children hold of the two experimental tasks investigated were obtained from transcripts of group work produced by twelve pupils. The analysis of the transcripts revealed that pupils did not read all the instructions to the experiment and instead of summarizing the procedure the groups were more content to use a recipe-following technique to set up the experiment. This confirms a tendency that Tasker (1981) has discovered in his research. Experimental tasks in most schools are performed in small groups and it was noted that the structure of the group influenced the perception that pupils had of the experiment. Practical work was seen as "assessable" by most groups and consequently the discussion of questions to be answered was seen as more important than reflection on the scientific procedures being used in the experiment. This assessable nature of school work reinforced the pupils' attitude that answers were required to fulfill the task of the lesson. Pupils' perceptions are related to the instructions of the experiment, the actions that are required and the results being observed. Consideration of these perceptions is important when investigating pupils' experimental work since these may influence the change in conceptual relationships within a pupil's framework.

The method by which the two groups embarked on the first practical task influenced the later discussion of their results. The boys did not read all the instructions. Although this may have saved time, it
prevented them from reflecting on the purpose of each stage of the experiment. It also required the pupil to take one informational item at a time and reflect on that in isolation and perform that instruction without any relationship to the others. Because the boys distributed the plates among each other, and appeared to place one pupil responsible for each plate, they lost sight of the overall structure of the experiment.

The choice not to read the whole of the instruction sheet at one time meant that when they reached instruction number seven they probably read "After two days..." and thought that that piece of information was redundant at the time. In fact it held an important concept i.e. that bacteria will grow in colonies and that after two days they will be visible to the naked eye. The lack of this information meant a different perception of the results and that Steven's query, concerning if you could see the bacteria growing immediately or not, was ignored and thought irrelevant. A more subtle reason may be that if they ignored this query they could answer the question about predicted results by looking at the dust marks (produced on the plates by the wind) that they mistook for bacteria. This was far simpler than trying to reflect on their actions and predict an outcome.

By taking a recipe-type approach to the experiment all pupils avoided actively generating relationships between the different aspects of the information in the experiment. As we have seen, pupils had problems understanding that the results of the experiment would not be instantaneous. This information was available to all pupils in the instructions of the experiment and could have been used by the pupils to
construct their own information and draw inferences. The procedure of putting plates in the incubator and waiting for two days could have confirmed this information, but instead, this was neither considered nor connected to the information provided and so was not fully understood.

The second experiment used similar scientific procedures so it would be expected that the experience of the first experiment would aid the performance of the second practical task. This experience apparently did help since the pupils were not so intent on following the instructions step by step. It was not possible to determine if the pupils restructured the experiment to see the task according to their own framework since this was not verbalized and recorded by pupils.

In many cases the "discussions" about methods and results by the groups of pupils did not involve pupils in actively listening to other members of the group. Neither did it involve testing other pupils' ideas against their own framework. There did not appear to be any attempt to construct meaning from sensed experience and concepts stored in long term memory. It was noticeable that if one pupil in the group was more respected either in an academic or social sense then his/her answers to questions would be approved with little reflection. The provision of an answer to questions appears to be important and pupils tend to be more answer conscious than wanting to share concepts that other pupils supply or attempting to generate links between new ideas and their own beliefs. It was also seen as important to finish the questions even if the answers were not as satisfactory to the group as they could have been.
The girls exhibited the most sensitive attitude toward assessment. Practically everything that is done in schools tends to make pupils answer-centred and the girls in particular showed this by editing their tape of any discussion passages. The other group of girls restricted their rejection of their potential answers and showed an urgency to fulfill the task of answering the rest of the questions. The chances are that we as teachers are answer-centred and do not realize the damage this does toward the pupil's attitude of reflective thought and how this centring can deter groups from listening to all its members reasoning. For example, if the first speaker provides a good answer - in that it is not too out of line with the other pupils' frameworks - then this can be found acceptable and there is no need to suggest, refine, or listen to any other argument. The manner in which teachers present work, plus the volume of work they assign can force pupils into these answer directed strategies. Another problem is that in general the pupils do not see the setting up of an experiment as work. Reflecting back on my own experience, if you take all of the lesson to set up and discuss an experiment then pupils will often volunteer that they did not do any work.

In summary, it would appear that pupils tend to avoid reflecting upon their own physical actions, beliefs and attitudes. This finding, in combination with the pupil's attitude to practical work and its assessment, should lead teachers to revise their presentation of experiments so that pupils become more problem centred and have an increased awareness of other pupils' viewpoints. Teachers need to present problem orientated tasks so that instructions, actions and results can all be understood by generating new linkages to concepts acquired through the experiment with those already in long term memory.
5.6 Conclusions

This study reveals that pupils possess a multiplicity of beliefs concerning the existence and functions of bacteria. The heterogeneity of beliefs is a result of the variety of subsuming concepts and the relationships of these subsuming concepts to each other. Prior beliefs about bacteria were found to influence the way pupils perceive the experimental procedures involved in the two experiments used in this investigation.

Difficulties related to explaining colony size revealed that pupils possess different types of beliefs for the concept of growth. Those pupils who constructed growth concepts primarily in terms of an increase in cell size had difficulty in explaining the reason for the variety of colony sizes. Those pupils whose beliefs about bacteria encompassed growth concepts related to cell division were able to explain colony growth with greater clarity. Many pupils were not able to provide more than two characteristics of bacterial life, but it was found that if they had a reasonably well developed notion of growth which included cell division or reproduction of bacteria this was a sufficient basis for success in interpreting the experiments.

Pupils appeared to be unable to explain how to show that the equipment was sterile. Those pupils appeared to be "overloaded" with the practical details (i.e. nature of the petri dish, etc.) of the experiment. Other pupils, although possessing concepts of bacterial life, presented alternative beliefs concerning the role of the sterile equipment and medium. Both practical details of the experiment and alternative beliefs
interfered with the interpretation of the significance of the sterile equipment, medium and the significance of the control plates in the two experiments.

Pupils often thought that the control plate was to be used as a comparison between the other petri dishes; a technique that could have been learnt from other science situations. The practical details of the experiment made pupils consider using the control plate to check that no bacteria were seeping into the dishes. From 58% of the class (those taking part in clinical interviews) only one girl and two boys used the control dish to substantiate that the agar and petri dishes were sterile at the beginning of the experiment.

It was found that pupils' reasoning to explain experiments was not simple and that their prior concepts about bacteria and those concepts acquired through the course of the experiments appear to influence the pupils' understanding of the experimental procedures of sterilization and controlling variables. The logical demands of the task were problematical to the pupils because the context in which these demands lay were providing stumbling blocks for understanding the experiments. The suspected interference of concepts in cognitive functions was proposed by Donaldson (1978) and this study supports her view. Charles' (1976) claim that the Nuffield Combined Science curriculum can be adopted to be used successfully with nearly the whole ability range in secondary school can be supported if prerequisite concepts demanded by the topic and its experimental work are identified and teachers assess pupils' prior beliefs to detect any weakness in these prerequisite frameworks.
Analysis of pupils' group work revealed interesting conclusions about pupil attitudes to practical work. Pupils spent little time reflecting on the practical processes of the experiment since their motivation lay in answering questions they thought were provided for assessment. The researcher gained little insight into pupil reasoning concerning the procedures of the experiment or the concepts pupils possessed from the written answers to the questions since the pupils were concerned with completing the written work and not reflecting on the quality of the task.

If teachers are interested in aiding pupils' learning then they need to be aware of pupils' prior concepts and how they are used in experiments. By asking the right questions teachers can help pupils to achieve meaningful learning, but if they ask the wrong questions - those that do not encourage pupils to reflect on their reasoning - then teachers are providing pupils with meaningless practical opportunities for concept acquisition. Providing opportunities for concept development would require a different emphasis on assessment and the nature of the tasks in the classroom.

5.7 Implications of the study

This section draws from the discussion and conclusions of this study and discusses the implications of the study on the teaching of laboratory based school science. Future research that may make practical lessons a more useful learning activity for pupils is also discussed.
5.71 Implications for teaching

Pupils' concepts

Laboratory experiments may be made more useful learning experiences if the knowledge provided by these activities is meaningful to the pupil. "To acquire knowledge meaningfully means that the learner must incorporate new knowledge into concepts that the learner already has" (Novak, 1980). This research has shown that pupils with inadequate concepts are unlikely to possess sufficient structural knowledge to incorporate new knowledge, provided by the experiment, into their framework. Teachers need to identify the concepts embedded in the experiments being used and then find out the extent to which these concepts are possessed by the pupils prior to the experiment. Pupil construction of concept maps may be a useful and less time consuming method of obtaining this information than using interviewing techniques. However, from interview and mapping methods it would be possible to ascertain if the knowledge structures in long term memory that may be used to generate meaning from a learning experience were inadequate or inappropriate. Tasker (1981) found that pupils' knowledge structures, against which learning experiences were considered, were frequently not those that the teacher assumed the pupil possessed. Using concept maps could provide the raw data about pupils' concepts and their relationships to other concepts and so possibly reveal this mismatch between knowledge structures and learning experiences.

Teaching strategies

It has been stated (Tasker, 1981) that pupils tend to consider each lesson as an isolated event and that they do not associate concepts embedded within the task as being linked with previous learning experiences. This pupil behaviour was exhibited by those pupils who did
not use their life concepts of multicellular organisms. Much of science practical work does not encourage the pupil to find links between knowledge in long term memory and incoming information. If pupils are asked to control all the inputs of working memory then they are dealing with 1) theory to be recalled,
2) skills to be recalled,
3) names of apparatus and materials to be recognized and associated,
4) new written instructions,
5) new skills, and
6) new verbal instructions.
This is likely to lead to an "overload" situation which can result in ineffective learning strategies characterized by one or more of the following pupil actions: recipe-following, copying the actions of others, or busy random activity (Johnson and Wham, 1982). "Overload" can result in theory applicable to the situation not being used. The teacher can help "chunk" incoming information for the pupil by turning the attention of the pupil toward the conceptual part of the information provided by the experiment and the methodological aspects of the experiment, prior to the experiment. Discussion along the lines suggested in Gowin's (1979) knowledge "V" organizes the thinking side of the V which is subdivided into events, concepts, principles and theory, whereas the doing side of the V deals with objects, records, transformations and knowledge claims. The knowledge claims provide answers to the question or problem in focus. The nature of this focus question would depend on the purpose of the lesson. Pupils have been known to generate a purpose for the learning activity which is very different from the teacher's intended purpose (Tasker and Osborne, 1983) so it would be useful to explicitly state the
purpose for the experiment in advance. Defining the purpose of the experiment in the focus question can lead to an examination of objects and events, theory and concepts so that new knowledge is constructed (Novak, 1980).

In the present study pupils showed little concern about the features of the investigation considered by the teacher to be critical design features. It may have been helpful for the pupils to have seen, prior to the experiment, the sterilization process of the plates and agar performed, the plates poured and left until the next lesson. This would enable the concept of sterile to be discussed in relation to other life concepts of bacteria and also perhaps overcome the problems caused by the loose fitting lids of the petri dishes.

In order to assess that the pupils' understanding of the experiments is the same as that of the teacher, a more sensitive method of assessment needs to be employed other than the normal answering of questions at the end of the task. It is suggested that the concept map provides an efficient method of gaining an overall picture of the extent to which meaningful learning has taken place and it also can be used to suggest future instructional needs. For example, one can look at the propositions that link concepts as being indicators of the measure of differentiation between constituent concepts. Nesting of concepts is another way of demonstrating relationships between concepts and this can be used as a measure of integrated reconciliation of meanings (Cronin et al., 1982). Even with less sophisticated analysis the teacher can ascertain the concepts held by the pupil and gain insight into the pupil's knowledge
structure for a given content area.

An alternative method to that of written questions for assessing pupil performance in the classroom is desirable since this study has found that pupils are more intent on completing work that is obviously assessable rather than reflecting on the overall intent of the experiment and their own individual actions which they know the teacher is not able to assess. The pupils' success or failure in understanding scientific ideas is dependent on their own actions. Pupils need to be willing to generate meaning for concepts and believe that the energy expended on the reflection of concepts and linking them to other beliefs already in long term memory will aid them in the development of an understanding of the ideas of science. Teachers can motivate their pupils to do this by encouraging them to become problem-centred. In order to encourage them to become problem-centred more emphasis needs to be placed on the importance of reflected thought rather than the answers to questions. For instance, the answer "bacteria will grow better in the incubator" (typical answer to question 7, Bacteria on Ourselves) tells the reader nothing about why this occurs or about the concept of growth that the pupil possesses.

Knowledge, learning and understanding are not linear. It's not just a matter of knowing all the items but of knowing how they relate to, compare with and fit in with each other. Written tests produced by the teacher, unless carefully devised, do not test the extent of these relationships. School work must be such that pupils' efforts in generative learning will lead to understanding.

Learning has been seen to be influenced by the learner's perceptions
and interpretations of the events the learner encounters. It may be necessary that written work have focus questions to explicitly state objectives to clarify the intent of a lesson and that instructions encourage the pupils to consider the important design features of an experiment. Pupils' achievement can be influenced by the questions teachers ask pupils or pupils ask themselves. Group work can help pupils by encouraging them to reflect on other perspectives of the task. Learning in groups is more likely to occur when pupils are not placed in a situation where assessment of non-reflective written work is demanded and, instead, pupils are encouraged to produce and present their own knowledge structures concerning the experiment.

The greatest implication that this study provides for teaching is that of teachers underestimating the power of prior beliefs that pupils bring to the classroom. Those pupils with adequate concepts found that after experiencing the procedures of the first experiment they could carry out and interpret the intent of the second experiment with success. If more pupils are to understand experiments then the concepts that are required for generating meaning from practical work need to be assessed and if these are found to be lacking in pupils' frameworks then instructional sequences ought to be designed to take account of these alternative frameworks.

5.72 Implications for research

Much useful research has been undertaken to uncover pupils' substantive beliefs concerning many physical science phenomenon. Less of this type of research has been involved with concepts in the biological
sciences. The concepts of life are important in all spheres of biological science and yet do not appear to have attracted much research attention. This study has revealed that the pupils' concepts of growth and reproduction in unicellular organisms can provide useful stepping stones to generate meaning or hinder comprehension in the two experiments studied. It is speculated that there are probably different beliefs held concerning growth and reproduction in simple one-celled organisms than those held in relationship to multicellular organisms.

More research is required into the way meanings are constructed, what motivates pupils to reorder their conceptual frameworks and embed them into long term memory. When faced with a problem solving situation pupils may use their concepts to construct a solution. In order to do this the pupil needs to understand the problem. Researchers should be asking themselves what is the nature of the problem constructed by the pupil? If a problem is not constructed then is this due to sensory information not cueing aspects of long term memory and how could this cueing procedure possibly work? This study begins to look at the strategies pupils employ in order to obtain a solution to problems. It also examines how the pupils' concepts can interfere with this process. There are many avenues of research open in this field that may provide useful insight into pupils' mental activity and help teachers devise teaching strategies accordingly.

If practical work is not to become an interlude for pupils from other class work in science laboratories then pupils and teachers must adopt different learning and teaching strategies. Investigations into how
reflective discussion may improve the motivation of pupils to generate meaning from practical work could provide key information as to which teaching strategies may be more useful. Research into pupil and teacher attitudes and beliefs about practical school science has already provided some evidence which may assist teachers in reflecting upon their own teaching strategies. This type of research has by no means come to a close and it is possible to look forward to further studies involving teacher and pupil participation with teachers becoming researchers in their own classrooms. This can eventually lead to improved teaching strategies within the individual teacher's classroom that may manifest themselves in the improvement of pupils' concepts of science.
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APPENDIX A1

Subject: Clive Clinical Interview One

Int.: I gave you a word search on diseases, well what are diseases then?
C.: Things that you can catch, bacteria give it to you.
Int.: How do you know about bacteria, where did you find out about bacteria? You know the word...
C.: Sort of a germ, germs give you different diseases.
Int.: Are all these diseases the same? What makes them different then?
C.: You can pick them up in different ways. Different germs cause different diseases.
Int.: How could you tell a germ from another germ?
C.: I don't know. I don't know.
Int.: Could you look at them and tell that they were different?
C.: Well you can't really see them unless they're under a microscope.
Int.: So they are very very small?
C.: Yea.
Int.: Are bacteria germs?
C.: Well yea sort of.
Int.: So what do you include as well as bacteria as germs?
C.: I don't know really.
Int.: So you don't have a definite idea of what germs are?
C.: No, not really.
Int.: These bacteria are they living things?
C.: Yea.
Int.: How do you know they are living?
C.: They've got to be haven't they.
Int.: Will no - there are lots of things that are dead.
C.: Well if they were dead they wouldn't be causing any illnesses because you get different germs inside you that kill them so you don't get the disease.
Int.: Is these a battle raging in your body between germs?
C.: Could be yea it depends.
Int.: What does it depend on?
C.: Well I saw this program, I can't remember what disease it was but they give you an injection of a certain disease, a very mild one. So you catch it and then your body builds up sort of antigerms to kill them. Then if you got the disease again you'll have the antigerms there ready to kill them.
Int.: That's good.
C.: I think it was hooping cough, measles, I can't tell you.
Int.: That doesn't give us a good reason why bacteria are alive?
C.: They produce don't they?
Int.: They produce.
C.: Yea.
Int.: They produce what?
C.: Other germs.
Int.: Oh, they reproduce.
C.: Yea reproduce that's what I meant.
Int. Ok. So you would count that as a major thing of
C.: And that's what
Int. Alive.
C.: And what's that stuff in here again...plac
Plaque.

Plaque - well that produces acid doesn't it. If they .. when they get anything sweet that produces acid.

So they are not only reproducing themselves they are producing other things.. waste

Some do

Yea waste things

Yea

Well why do some do that and others don't?

I don't know.

Ok

Well maybe because some get things like germ plaque take in sugar - but the others may not take in anything.

But if they don't take in anything would they be alive? Don't all living things need food?

I don't know.

What could these other bacteria live on if they don't live on sweet things?

Other germs, I think inside your body.

Would you only find them in your body - these bacteria?

Bacteria?

Yes.

No.

Where else would you find them?

On your skin - I saw another thing in a magazine as well that there's about a thousand of these little things in every square millimetre of your skin and it showed up a piece of skin - a tiny piece of skin you could see them all over your skin.

Gosh they must be very small then.

Yea.

Could they be anywhere else?

I don't know really.

Where would we pick them up from if they are on our skin?

On our skin?

Yea you said there were hundreds and thousands on our skin.

Well I don't know where we would pick them up. We probably just get them automatically.

Well you said we could use other bacteria to prevent us from getting diseases.

Well yes, it's like injections. Cause I went to Holland and I get asthma if I go near cats because I'm allergic to them. And I went to Holland and they had two cats and I had really bad asthma. So I had to go back to the doctors and he said I had to go back to Germany and he gave me an injection before and then I was alright then.

I see.

Its the same with hooping cough and that - you have injections when you're - I saw a program on that- I see a lot of programs. It was when I was away last week I was watching this program and it said you have an injection when you're six months, another when you're one, and another when you're three and then at five you have a booster and you should be rid of hooping cough.
Int.: You should be rid of it does ...
C.: Well it doesn't mean that there's no chance of you getting but it sort of means that there is less chance of you getting it.
Int.: So that means all these diseases that we've been talking about must be passed on somehow.
C.: Yes, breath. If you breathe or if you've got a cough and you cough at somebody then they'll catch it. It can be passed on by touch.
Int.: Do you have to touch people to get these diseases?
C.: No, not really, you could touch anything.
Int.: So the bacteria are not only on you but on something else.
C.: Yes they could be.
Int.: They are on other things.
C.: Yes.
Int.: What happens if they are not killed?
C.: They just keep well they go on and on. I'm not sure really. Well in the end they die. Like chicken pox you can't do anything about them except but what's it called again sort of plaster of paris
Int.: Oh, Calamine
C.: Calamine lotion on them because I had that. They die off in the end. If you scratch them then they mark and they stay there for life.
Int.: What?
C.: The marks, just the marks.
Int.: Are the marks the bacteria?
C.: Well I don't know. The bacteria cause spots.
Int.: Oh they cause the spots.
C.: The sort of spotty lumps.
Int.: Ok. that's good.
APPENDIX A2

Sharon's Propositional Statements

Bacteria cause disease
Bacteria are living
Living because - they form plaque in teeth
- they come back all the time
- can eat off cells
Bacteria grow in fridge
Bacteria reproduce
Bacteria are found in food
Bacteria are very small

Bacteria are jelly like, transparent
Bacteria can be different shapes
Bacteria may be red or white
Plaque on teeth is bacteria
Can help make vaccinations to fight disease

Concept Map
Neil's Propositional Statements

Diseases caused by bad habits
  worms, tsetse fly
Colds - contagious have to give them away before it goes.
  - caused by water
Medicines - work by breaking down cells -
  - affect bad cells
  - Bad cells attack good cells

Concept Map
Mark's Propositional Statements

Diseases are caused by dirt germs
Germs caught in cold environments, water
Cold caused by germs
People spread germs
Animals have germs on their bodies
Germs would go into cuts
Spread in body

Not big enough to see
Look at them through a microscope
Some germs are bigger than others
Some germs are more detailed
Germs live in animals and the earth

Concept Map
Justine's Propositional Statements

Germs cause disease
Germs cause colds
colds caught in wet weather
Germs cause food poisoning, worms in food cause disease
Germs live inside people, water, air, food

Different types of diseases caused by different types of germs

Medicines kill the germs

Germs are living
They are living because they cause disease
People spread disease by coughing and breathing
People develop "immunity" to disease

Concept Map
Clive's Propositional Statements

Bacteria give you diseases
Bacteria are a sort of germ
Different germs cause different diseases
Can't really see them unless they're under a microscope
They can be passed on by breathing, touching
If dead wouldn't cause illness
Different germs kill other germs
Antigerms kill germs
Injections prevent you getting diseases
Antigerms built up in body
They reproduce
Plaque produces acid
Germ plaque takes in sugar
Not all germs need food

Found all over skin
They are automatically picked up

Concept Map
APPENDIX B

Experiment One: Bacteria in the Air

For this experiment you can work in pairs, each member of each pair should wash his hands before the experiment.

You will be provided with petri dishes containing sterilized agar. The dishes have also been sterilized. This means that they are absolutely clean.

1. Label the plates 1, 2, 3 and 4.
2. Choose a draughty place in the laboratory, take off the lid and expose the agar of plate 1 to the air for twenty minutes.
3. Choose a place in the laboratory where there are no draughts, take off the lid and expose plate 2 to the air for twenty minutes. You should make a draught screen for this plate by surrounding it with a ring of card-board.
4. Expose plate 3 outside for twenty minutes.
5. Do not expose plate 4 at all.
6. Bacteria grow best at about 37°C, so place the plates in an incubator, at this temperature.
7. After two days remove the plates from the incubator. If bacteria have fallen from the air onto the exposed plates they will grow into colonies, and since the agar is transparent, there is no need to lift the lid off the petri dish to see them. Place the whole plate on a piece of black paper and the colonies will show up beautifully.

Experiment Two: Bacteria on Ourselves

For this experiment you can work in pairs. One member of each pair should not wash his hands before the experiment. You will be given 3 petri dishes. Label these A, B and C. Each dish has been sterilized and contains sterilized agar.

1. Label the 3 petri dishes A, B and C.
2. **Plate A** The person with washed hands opens A, while their partner, with unwashed hands very gently presses the fingers onto the agar jelly so as not to damage the surface. Replace the lid quickly.
3. **Plate B** The person with washed hands opens the lid and presses the fingers of one hand very gently on the medium and then replaces the lid.
4. **Plate C** Leave unopened.
5. Put the plates in the incubator at 37°C.
6. After two days examine the plates.
Clinical Interview Two "Bacteria in the Air"

Steven

The interview with Steven began by recapping the experiment.

Int: What was the point of sterilizing the dishes and the agar before we started?
S: I think that you sterilize the dishes and then the agar because it would stop any other bacteria getting into the agar or into the dishes. And that bacteria we don't want. We want the bacteria from a certain place.

Int: OK. So are we sterilizing the bacteria that are already on the glass and in the agar?
S: Er, what we're doing is that we're sterilizing the dishes and the agar to get out all the other bacteria that we don't want.

Int: OK, and why did we clean our hands before?
S: We cleaned our hands before we started so that, so that no bacteria would get on the glass or the agar which wasn't wanted.

Int: So did we have bacteria on our hands then?
S: Yes.

Int: And they might get onto the agar.
S: Yes.

Int: Why do you think we decided to put one in a draughty room and one in a non draughty place?
S: If we have one in a draughty room it can tell us how much bacteria is getting into the air round there and in a non draughty place it can tell us how much bacteria is just floating around.

Int: OK, fine - and why did we leave the plates open for so long?
S: Oh, if we opened them for just 2 or 3 seconds the bacteria wouldn't have much chance to get onto it so we had to leave them for twenty minutes so that bacteria could settle onto it.

Int: OK, so we'd have more chance of getting more bacteria then?
S: Yes.

Int: Now what was the purpose for having plate 4?
S: Now I think the purpose for having plate 4 was so that we could see if bacteria seeped in through the glass, through the gaps or even through the glass onto the agar.

Int: Did it tell us anything about the dishes before we started the experiment?
S: What do you mean by that?

Int: How do we know whether the dishes were sterile before we started the experiment?
S: If you put it in the pressure cooker it is bound to get rid of the bacteria because of the steam and the pressure.

Int: How do we know it's bound to? Something might have gone wrong. How would we know if anything went wrong?
S: I don't know.

Int: OK. What kind of explanation can you give for these results here?
S: Well, on number one it shows that we have had a lot of bacteria.
Int: This is the one that's outside.
S: Yes, and it's all built up in colonies and they're all different colours.
Int: Do you think there are different types of bacteria in there?
S: Yes, I think that flower—one, it looks like it is different to that yellow smeared one.
Int: Yes. OK. Why are some big and some small?
S: I think it depends on how quickly they divide or it could be the bacteria in the air and how much there is of each.
Int: OK. So there are lots of bacteria in each of those colonies?
S: Yes.
Int: What about the differences between the draughty place, number 3 and number 2, the non draughty place?
S: I think that in the non draughty you would get more because of the, because of the um, well it isn't draughty so the bacteria just goes down, but in a draughty place the bacteria goes over it, but if you put it outside bacteria also goes over it and it slows down and goes in. In a draughty place it's always draughty all the time.
Int: OK, that's fine.
Clinical Interview Three "Bacteria on Ourselves"

Mark

The interview with Mark began by recapping the experiment.

Int: What do you think the results are going to be?
M: Well, I think that dish A that was the dirty hands would have a lot of bacteria on it because I've got a lot of bacteria on my hands 'cause I haven't washed them recently. Plate B, the one with clean hands, will have hardly any because he washed his hands a few minutes before he put his hands in the jelly.

Int: So you think the washing will get the bacteria off?
M: Yes, well some of it, most of it will come off but some of it will stay there.

Int: So that explains why some will be on the jelly.
M: Yes.

Int: How about Plate C?
M: Plate C I don't think will have any.

Int: Why don't you think it will have any?
M: Because it was closed in a jar, in a plate but some could seep because if they were floating in the air and it wasn't cellotaped up and it wasn't sealed in so I don't think some bacteria might have been able to come in from the air, but it would spoil the experiment.

Int: Why would it spoil the experiment?
M: Because we are doing it on ourselves.

Int: How could you tell if the bacteria got in from the air or from ourselves?
M: Well, I don't know really. There's two different kinds of bacteria, probably the one in the air you know, you know is detailed. Got lots of you know dirty marks and that, but on your hands it probably hasn't got very much you know because you wash them. I wash them after breakfast but if you wash them you'll still have bacteria on them, some are useful bacteria.

Int: Did it matter that the plates were sterile when we started?
M: Yes, because if they weren't clean the bacteria from the air and your hands would get in there before the actual experiment because we are trying to find out that bacteria are on our hands and not in the air.

Int: How could we tell if the bacteria had got in before the actual experiment?
M: Well, you would probably see the splodges like grit in the dish.

Int: What was the use of having plate C if we didn't even open it?
M: Well, to compare the answer, to compare the difference you can see whether C does have more bacteria or less than the other two. See if plate C had less than plate B and A or more than plate B and A.

Int: You said that you thought there wouldn't be any bacteria in there.
M: Well, there might be a little bit because it might you know - bacteria is floating about how so it might you know come into plate
C. You know come up through the gaps.

Int: Would that matter to the experiment?

M: Well yes, really because you're testing bacteria on yourself on your hands and if it came in from the air then it's not from yourself although if bacteria's floating around now it might get on your skin so really bacteria from the air might get onto yourself you know it's a guess but it might do.

Int: But it would be important that those plates were sterile at the beginning.

M: It would otherwise it would spoil the experiment because you're not testing what's in the air if you did that you're testing the bacteria on your hands

Int: OK. Last question. Why do you think we put them in a warm place?

M: To keep them at body temperature because you put them in a warm incubator at 30° at 37° and that's our body temperature.

Int: So the bacteria would like to live at body temperature.

M: Yes.

Int: Fine.
Class Experiment One  "Bacteria in the Air"  Group A

Mark
Martin
Robert
Steven

Robert:  (reads) "Choose a draughty place in the laboratory, take off the lid and expose the ..."
Mark:  Open the window - draughty place.
Steven:  Yes, there is.
Robert:  It says put the first one
Mark:  Plate One
Robert:  "Expose it to the air."  Yes, plate one.
Mark:  "For twenty minutes".  Right on your marks get set.
Robert:  I'll time it.
Steven:  Look, there's a clock up there.
Mark:  Alright, what do we do now?
Robert:  Haven't you got something to put 'round it?
Mark:  No.
Steven:  You put both plates out don't you?
Robert:  No, only one.
Steven:  Look at the jelly.
Mark:  What do we do with the other one?
Robert:  Choose a place in the laboratory where there are no draughts.
Mark:  "Take off the lid and expose the plate 2 to the air for twenty minutes" - but there's no draught.  "You could make a draught screen for this plate by surrounding it with a ring of cardboard".
Robert:  Use the paper.
Martin:  I'll do the card.
Robert:  "Expose plate 3 outside".
Steven:  I've done that, it's outside on the ledge.
Robert:  Right.
Mark:  What's this?
Robert:  That's the question sheet, we'll do that afterward, we'll do this first.
Mark:  OK, right.
Steven:  What about the labels - we label them don't we?
Robert:  Do we label them?
Mark:  We do.
Robert:  I'll label them.
Mark:  Plate One is on the what shall we
Robert:  Put plate One - I'll do the writing.
Mark:  Plate Two.
Robert:  I'll do the writing up of ideas.
Mark:  OK, you go on then put it on number one.
Robert:  It's outside.
Steven:  Does it lick on?
Mark:  Yes - Two, Three - we've only got three.
Steven: Yes.
Mark: There, do it on number two, do it on the lid of number two.
Martin: What was in that one?
Mark: Er.
Martin: What was in that one? Was that the lid?
Mark: The jelly, it's the jelly.
Martin: What are we doing?
Robert: What we are doing is testing for bacteria and we've got some jelly here.
Mark: And on the windowsill in the draught.
Robert: We're testing the bacteria in the air. And here we're going to exclude draught from the jelly and see,
Mark: For twenty minutes.
Steven: No, it doesn't
Mark: It is.
Martin: How are you going to test what bacteria's in that one?
Steven: It's going to take two days.
Mark: Well this will test if there's bacteria in the air, won't it?
Robert: Yes.
Mark: And this will test to see if there's bacteria just floating about and not in the draught. What is number three then?
Robert: We've done number three.
Mark: What is number four then?
Robert: Expose plate three for twenty minutes outside.
Steven: It is outside.
Robert: No, that's the draughty place.
Steven: Choose a draughty place in the laboratory, near the door.
Robert: Is it draughty?
Steven: It must be.
Mark: It said outside though.
Steven: No look, I'll show you, it says - look, choose a draughty place in the laboratory, take off the lid, expose plate one.
Mark: That's plate three outside.
Robert: That's plate one.
Mark: We'll remember that. Go over it with a pen, a blue.
Steven: That's better.
Robert: I'll go and change the other one.
Steven: Have you put the number on that one?
Martin: Why do you have to go over it with blue?
Mark: Feel like it.
Martin: Why?
Mark: Make out a number three. I'll put it outside, right.
Steven: Not outside - in a draughty it said.
Mark: Give it here.
Steven: As long as no one comes in we are alright.
Robert: Where's the lid? Hey you guys, have you taken the lid off plate 4?
Mark: Have we got a plate 4?
Robert: Because it says don't take the lid off.
Mark: We haven't got one anyway. Bacteria grow - after two days remove the plates from the
Steven: Incubator - it's got to go in an incubator later.
Mark: If bacteria
Robert: We want to do all our ideas now don't we?
Steven: Hang on, wait a minute.
Robert: Number one, why do the petri dishes, what's that oh dishes and agar absolutely clean before the experiment began?
Mark: Because otherwise the bacteria will be on.
Robert: I'll write it. What'd you put then?
Mark: Answers answers at the top.
Steven: Answers and then put if you didn't wash it clean it first there'd be already bacteria on it.
Robert: If the agar solution wasn't absolutely clean before the experiment
Martin: Sterilized, sterilized.
Robert: Absolutely sterilized.
Mark: There might be bacteria.
Steven: There will be bacteria, bacteria's everywhere.
Mark: There would have been bacteria in it already.
Robert: Yes.
Martin: On it.
Mark: In it.
Steven: It is in it as well.
Mark: Now what's number two?
Robert: Why did you have to have clean hands at the beginning of the experiment?
Steven: Otherwise they'd have bacteria and might spread it in.
Mark: We'd spread the disease in wouldn't it.
Robert: Your hands were cleaned because we would have had bacteria on our hands.
Mark: Three, three A.
Steven: Why were dishes opened in a draughty place.
Mark: The dishes were opened in a draughty place
Robert: The dish were opened in a draughty place (writes)
Steven: To test if there is bacteria in the wind
Mark: In the air.
Steven: To test for wind bacteria because look we had a draught.
Robert: To test for bacteria in the wind (writes).
Mark: A draughtless place
Martin: To see
Mark: To test for bacteria in calm air.
Robert: To test for the presence (writes)
Mark: For the presence?
Martin: Yes.
Mark: For the presence of bacteria of bacteria. What did you write for B?
Robert: The dishes were placed in a draughtless place to test for the presence in a draughtless place.
Mark: The plates were left open for a long time - I think we'll have to wait for the twenty minutes before we can answer this bit.
Robert: Yes - Is there a purpose for plate four - if so, what is it? We didn't have plate four but I know why. Look here, do not expose plate four at all.
Int: Right, I'm just going to say they're all upstairs. I didn't give them to you because I didn't want you opening the lids.
Mark: Yes.
Int: So you've got 1, 2, 3 and there's a fourth plate sitting upstairs whose lids have never been taken off.
Steven: Miss, there's a plate outside.
Mark: Do we answer this, do we answer question four then?
Int: Yes, you can answer that.
Steven: Was it because
Robert: The plates were left open for a long time, why was this?
Uh, so that bacteria could get in.
Mark: So bacteria could get in.
Steven: Seep into the container.
Robert: So that the
Steven: Have you seen plate 3, it's got all bits of dirt in it.
Robert: The plates were left open for a long time because so that the
bacteria could seep into the agar.
Martin: To see if bacteria could get in.
Mark: Seep in.
Martin: Through a closed
Robert: Plate four was unopened to test if bacteria could come through
the glass? Anything else?
Mark: Something about if being no bacteria? does it change after being
kept for a while?
Martin: Bacteria could seep into the closed container.
Steven: Yes.
Robert: If you could break into the seal.
Mark: Lang's just messing around.
Robert: I know, and blabbing into this recorder is important. If you
could break into the sealed container can you imagine what the
results will be
Mark: Yes, those
Steven: Those exposed to the most volume.
Martin: Those exposed to the most draughty place will have the most
bacteria because in this room there are more humans.
Mark: A fast draught wouldn't have time to land on it.
Robert: Let's have a look at number three.
Mark: This is the worst one exposed to the most air.
Robert: The one exposed to the most air
Steven: Is that bacteria?
Robert: The one exposed to the most air
Steven: Hey look, is that bacteria?
Martin: Or the draughtiest place
Robert: Of course it's bacteria. I wish you'd stop showing off in front
of the tape recorder Steven.
Steven: I'm not showing off.
Mark: The, the
Martin: The plates that are exposed to the air
Robert: The plates that are exposed to the most air will contain
Mark: Will contain the most bacteria
Robert: Will contain the most bacteria.
Mark: Got two minutes to go.
Robert: One minute.
Mark: Shall we turn the tape recorder off?
Robert: No, leave it on.
Mark: You don't mind being turned off do you? We'll play it back
when we've done.
Robert: Stop, bring it in. You can have plate one, you plate two, you
plate three. Say about your plate into the tape recorder.
Steven: It says you have to wait two days in an incubator.
Mark: Just say what the results are now.
Robert: Here are our results now after exposing our plates to certain whizzes and air.
Steven: On plate one we have a swirl effect with minute pieces of dust.
Robert: What was plate one, where was it?
Steven: And plate one was outside our room near a draughty door.
Mark: Plate two was -
Robert: Plate two, yeh.
Martin: Plate two was not exposed to the air.
Robert: But it was in it was...
Mark: Plate two was not exposed to the air, we had
Robert: We had a ring of paper round it to keep out any draught or
Steven: It hardly got any bacteria.
Robert: There is a little bit on it because there wasn't a sealed container over the top but there's not as much as on the others and plate three?
Mark: Plate three seems to have a lot of bacteria on it because it was outside on a ledge and has grains of dirt from the wind blowing bacteria onto it.
Martin: Right, is that it?
Robert: Yes.
APPENDIX D2

Class Experiment Two "Bacteria on Ourselves" Group B

Chris
Andrew
Michael

** un intelligible vocalizations

Andy: Right, I'll lift up A and put my dirty hands in.
Chris: Press them in, press 'em in.
Andy: Ow.
Chris: You got to press 'em.
Andy: ** do you close A?
Chris: Yes.
Michael: Right.
Chris: Plate B, the person with washed hands opens the lid and presses the fingers of one hand very gently on the medium and then replaces the lid.
Andy: Er, feels like slime or something, er feels like snot.
Michael: Er, smells of something, er smells of disinfectant.
Chris: Put that back.
Michael: Plate C leave unopened. Put the plates in an incubator.
Chris: Where's an incubator?
Michael: Not an incubator. Where's the incubator then?
Andy: I'll go and ask her what to do.
Chris: Go and ask Miss. Got to answer the questions now haven't we?
Michael: Where's the incubator?
Andy: We haven't got one.
Chris: We haven't got one - questions.
Andy: Won't be long.
Michael: (reads) Questions. "Try and write down your ideas about the questions on the plastic overhead projector sheet".
Andy: Hey (whisper) got to ** *
Chris: Come on.
Andy: Ask her if you got to record this bit?
Chris: Where's the incubator Andy?
Andy: Don't know - she put them in there I think.
Michael: Try and write down yor ideas about the questions on the plastic overhead projector sheet. Your group may be asked to present their ideas to the class so think out your ideas carefully. If the person handling the plates
Andy: We've got to be recorded answering the questions.
Chris: That's what we are doing, we are being recorded.
Michael: If the person handling
Andy: Are we?
Michael: The plate, what's that?
Chris: During the experiment did not wash their hands before the experiment would it make any difference to the result?
Andy: Yes.
Chris: Yes.
Andy: Because
Michael: Number one
Chris: Yes, because then both of them would be the same and you couldn't tell the difference.
Andy: And then you couldn't compare a dirty hand to a clean hand.
Michael: Yes, that's true.
Andy: The living organism
Chris: Then - then you can compare what? Compare the clean hand with the dirty hand.
Michael: Oh my god, there's a frog, a frog in there.
Andy: Turner come and sit here, I can't be near that frog.
Michael: Why?
Chris: To a dirty hand.
Andy: Lift this and put your hand in the water.
Chris: Number two. Where's the frog?
Michael: In that jar.
Chris: Oh, I've seen that before.
Andy: Uggh, it's vile.
Michael: It's vile.
Chris: Number two, why did we have plate A unwashed hands?
Andy: The person with washed hand opens it up so that when the so that the person
Michael: Oh, just farted - sorry.
Andy: Got to answer this. Why did we have a plate A unwashed hands? Because. So we can compare it with B that is washed. Write it down you tit.
All: (giggles and laughs)
Chris: Go on, what did you say? No, keep it on.
Michael: Just 'cause you keep swearing.
Andy: Right, why did we have a plate A unwashed hands? So that we can compare it with plate B that has unwashed hands right?
Michael: (giggles) Yes.
Andy: Stop laughing.
Michael: Stop prancing about like a baby.
Chris: So we can compare it with plate B.
Andy: Why did we have a plate B washed hands?
Chris: So we can compare it with plate A.
Andy: So we can compare it with plate A.
Michael: Excellent.
Andy: Hurry up, write it down.
Chris: (writes) Compare it with plate A.
Andy: Would you expect to see a difference in results between the two plates, why?
Chris: Yes.
Andy: Yes, why?
Chris: Because one will have more bacteria than the other.
Andy: Good answer there Chris. Glad you thought of it.
Michael: Hey look, stick insects in here as well
Andy: It's like a zoo.

(Diversion while everyone looks at stick insects)

Andy: Do you think bacteria will grow on plate C?
Michael: No.
Andy: No, because ...
Chris: No, because it hasn't been opened.
Andy: Because it hasn't been, well it might have been.
Chris: Yes, because the bacteria
Michael: Plate C.
Chris: I know, because the bacteria could be out, could get through onto the plate.
Andy: No, I don't think so.
Chris: No, that's no good.
Andy: Just put no.
Chris: Well I think it should.
Andy: Well you're wrong.
Michael: Two against one.
Chris: What's number five? No, what's number six?
Andy: Eh?
Chris: What's question number six? Why do you think we had plate C?
Andy: We just did that.
Michael: Hold on, we just did that.
Andy: Why do you think we had plate C? Er, to ...
Chris: Because we could.
Andy: To see if bacteria could grow in plates taped up?
Michael: Yes.
Chris: Come on question number seven, we are on the last one.
Andy: Why are the plates placed in a warm incubator?
Chris: So that
Andy: It can breed.
Chris: So that the bacteria can breed and grow.
Andy: Switch it off, we've stopped.
APPENDIX E

Examples of Work produced from Groupwork

Experiment One: Bacteria in the Air

Questions:

1. Why were the petri dishes and agar absolutely clean before the experiment began?
2. Why did you have to have clean hands at the beginning of the experiment?
3. Why were the dishes opened in
   a) a draughty place (plate 1)
   b) a draughtless place (plate 2)
4. The plates were left open for a long time, why was this?
5. Is there a purpose for plate 4? If so, what was it?
6. Can you imagine what the results will be?

Answers:

Example A

1. The dishes had to absolutely clean before the experiment began so that no germs or bacteria got in there.
2. We started the experiment, with clean hands, so that to prevent getting bacteria on the plates.
3. a) The dishes were opened in a draughty place so that they could get bacteria from which is carried in the wind.
   b) The dishes were opened in draughtless place so that they could get bacteria from the air in a room.
4. Yes we do think that there is a reason for plate 4 so that you can see the difference between the exposed and the non exposed.
5. We imagine that the results will be all different because of the different place that they were in.

Example B

1. So that no germs could create on the dishes and they would be sterile.
2. We had to have clean hands because we didn't want to get germs or dirt inside our petri dishes.
3. a) The dish was opened in a draughty place because the air had to get to it.
   b) The dish was opened in a draughtless place so air can only get in from the top.
4. The plates we exposed for a long time were like this because the germs had to get into the plate.
5. Yes there is a purpose for plate 4. No bacteria can get to it.
6. We think the plate outside will have a lot of germs on it. The one in the card will have quite a lot of germs on it, and the ones which were covered the whole time had no germs on them.
Example C

1. If the petri dishes and agar solution wasn't absolutely clean when the experiment began there would have been bacteria in it already.
2. Clean hands were needed because we would have had bacteria on our hands.
3. a) The dishes were opened in a draughty places to look for bacteria in the wind.
   b) The dishes were opened in a draughtless place to look for the presence of bacteria in a draughtless place.
4. The plates were left open for a long time so that bacteria could seap into the agar.
5. Plate 4 was unopened to test if bacteria could seap into the sealed container.
6. The plates exposed to the most air will contain the most bacteria.

Experiment Two: Bacteria on Ourselves

Questions:

Try and write down your ideas about the questions on the plastic overhead projector sheet.
Your group may be asked to present their ideas to the class so think out your ideas carefully.

1. If the person handling the plates during the experiment did not wash their hands before the experiment would it make any difference to the result?
2. Why did we have plate A? (unwashed hands)
3. Why did we have plate B? (washed hands)
4. Would you expect to see a difference in results between the two plates? Why?
5. Do you think bacteria will grow on plate C?
6. Why do you think we had plate C?
7. Why are the plates placed in a warm incubator?

Answers:

Example D

1. Yes the plates would be different because we would collect germs that we did not want.
2. We had plate A so we could see the difference between plate A and plate B.
3. We had plate B so we could see the difference between plate B and plate A.
4. Yes we would expect to see a difference between the two plates because on plate A we would expect to see germs and on plate B we would expect not to see any germs.
5. No, we wouldn't expect to see germs on plate C because it has not been opened unless germs can get through to it.
6. We had plate C to see if the germs could get into the agar and to
see the difference.
7. The plates were put in a warm incubator so that the germs could grow if any.

Example E

1. If the person that washed their hands didn't wash their hands plate A and B would be the same because plate A the person who didn't wash their hands put the fingers in the jelly and plate B the person who did wash their hands put their fingers in the jelly.
2. We had plate A for unwashed hands so that we could see how much bacteria was on your hands.
3. We had plate B so that we could compare to see if the bacteria was still there after washing your hands.
4. Yes we would expect to see a difference because the unwashed hands had more bacteria on them and with plate B most of the bacteria was washed away.
5. We think that very little bacteria will get into plate C because it hasn't been opened the only way it could get through is by a gap in the jar.
6. We had plate C just to see if it was possible for bacteria to get in.
7. The plates were placed in a warm incubator so that the bacteria would grow at the same rate as on our hands.

Example F

1. Yes, if the person handling the plates during the experiments did not wash their hands before the experiment when he opened the lid bacteria would get in from the hands.
2. We had plate A (unwashed hands) to compare with plate B (washed hands).
3. We had plate B (washed hands) to compare the difference with plate A (unwashed hands).
4. You would expect to see a difference in results between the two plates because unwashed hands would have a lot of bacteria but washed hands would have very little.
5. No, bacteria will not grow on plate C.
6. We had plate C to see if bacteria could seep into the plate.
7. The plates were placed in a warm incubator to keep them at our body temperature.
APPENDIX F

Examples of work produced from Homework

Experiment One: Bacteria in the air

Questions:
1. Why were the petri dishes and agar absolutely clean before the experiment began?
2. Why did you have to have clean hands at the beginning of the experiment?
3. Why were the dishes opened in 
   a) a draughty place (plate 1)
   b) a draughtless place (plate 2)
4. The plates were left open for a long time, why was this?
5. Is there a purpose for plate 4? If so, what was it?
6. Can you imagine what the results will be?

Answers:

Nicole

1. The petri dishes and agar had to be absolutely clean before the experiment began because otherwise if any other bacteria got on it that we didn't want we wouldn't get the results we wanted.
2. We had clean hands before the experiment because if you didn't bacteria from your hands would get onto the dishes.
3. a) Plate 1 was opened in a draughty place because then we could see what bacteria gets carried in the wind.
   b) Plate 2 was opened in a draughtless place because we could see what bacteria was in the air around us.
4. The plates were left open for a long time because we had to make sure alot of bacteria got on the plates.
5. There is a purpose for plate 4 it is-: plate 4 was left unopened because you can see the difference between plates 1, 2 and 3 against plate 4.
6. I imagined that the plates except plate 4 would have small blobs on them and they would all kind of lines over them.

Mark

1. The petri dishes agar were absolutely clean before the experiment because bacteria would be on the dishes already and would spoil the experiment.
2. We had to clean our hands, because bacteria would be on them and the agar would get bacteria on it when we touched it.
3. a) The dish was opened in a draughty place to see what the bacteria is like in the wind.
   b) The dish was opened in a draughtless place to see what the bacteria is like in a place with no draughts.
4. The plates were left open for a long time because then bacteria would have a chance of settling in the agar.
5. There is a purpose for plate 4. You can compare the 3 plates exposed to air and plate 4 which was not exposed to air.
6. You can imagine what the results will be. The dishes exposed to the most air will have more bacteria than the dishes exposed to not much air.

Robert

1. The petri dishes and agar were absolutely clean before the experiment began because bacteria would be on them and they would show up in the agar. These bacteria would be the wrong bacteria, as we were searching for bacteria in the air.
2. You have to have clean hands at the beginning of the experiment because the dirt and bacteria on them would show up on the petri dishes, so spoiling the experiment.
3. a) The dishes were opened in a draughty place to test for bacteria in a draught, to see whether they accumulate in a breeze or in still air.
   b) And the dishes were opened in a draughtless place to test for bacteria in still air, and so that it could be compared with dishes placed in draughty places.
4. The plates were left open for a long time so as to let the bacteria settle.
5. There was a purpose for plate 4. This was to see if bacteria could seep into the sealed jar, and so that it could be compared with the opened dishes. This would show the presence of bacteria in the air.
6. The results will be that those dishes exposed to more air will have the most bacteria on the agar.

We got the results we drew because the dishes exposed to the most air had more bacteria on them, because more bacteria passed over and on them.

Experiment Two : Bacteria on Ourselves

Questions:

1. What are the results for plates A and B?
2. Why do you think you got these results?
3. Have any bacteria grown on plate C?
4. Give a reason for your answer.
5. Are there different types of bacteria growing on plates A and B? Explain your answer.
6. What things could affect the growth of bacteria in the dishes?
7. Did it matter if the plates were sterile before the experiment began?
8. How could you prove that they were either sterile or not sterile?
**Answers:**

**Nicole**

1. The results for plate A and B were bacteria had grown inside the agar. They were small dots.
2. We got these results because they had germs and bacteria on them.
3. There shouldn't be bacteria on plate C.
4. No air has got into plate C because we never opened it.
5. There are different types of bacteria because one person washed their hands and one person didn't.
6. Heat could affect the growth of bacteria.
7. It did matter if the plates were sterile.
8. You could prove they were sterile because they had jelly in them.

**Mark**

1. The results from plate A and B are that B (washed hands) has less bacteria than plate A (unwashed hands) though there is not that much difference.
2. I think I got these results because dirty hands have more bacteria on them than clean hands.
3. No bacteria has grown on plate C.
4. The reason for this is because we kept the plate sealed, and so no bacteria could get in.
5. Yes there are different types of bacteria growing on plates A and B, A has got "splodges" and big cells and are on their own but B has got lots of little ones stuck together.
6. Air could affect the growth of bacteria in the dishes.
7. Yes, it did matter if the plates were sterile before the experiment began.
8. You could prove that the dishes were sterile or not because plate C was sterile and so were B and A, C was clean.

**Robert**

1. The results for plates A and B are that B, washed hands, had less bacteria than A, unwashed hands, though there is not that much difference.
2. I think we got these results because dirty hands have more bacteria on them, than washed hands have.
3. No bacteria have grown on plate C.
4. The reason for my answer is that the plate was sealed, so no bacteria could get in.
5. Yes, there are different types of bacteria growing on plates A and B, because there are different types of bacteria on dirty hands, than there are on clean hands.
6. The things that could affect the growth of bacteria in the dishes are the air, if there was none, so the bacteria couldn't breath. This would happen if the lid was sealed. If food, such as agar, wasn't present then the growth of the bacteria would be affected.
7. It did matter if the plates were sterile before the experiment, because unwanted bacteria would be on the dishes, so spoiling the experiment.

8. You could prove that they were sterile or not by adding some agar solution. Any bacteria present would grow and would be able to be seen. If none grew then the dish would be sterile.